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Restoration of Eastern White Pine (*Pinus strobus*) at Mille Lacs Kathio State Park, Minnesota

Kyle Arola

St. Cloud State University, kyle.arola32@gmail.com

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Restoration of Eastern White Pine (*Pinus strobus*) at Mille Lacs

Kathio State Park, Minnesota

by

Kyle R. Arola

A Thesis

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St. Cloud State University

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Thesis Committee:
William Cook, Chairperson
Jorge Arriagada
Jeffrey Torguson

Abstract

Eastern White Pine (*Pinus strobus*) was once a predominant component of the forest ecosystem in eastern Minnesota; however, widespread logging operations and associated wildfires removed significant amounts of white pine from the landscape at the turn of the 20th century. There has been an ongoing restoration effort at Mille Lacs Kathio State Park since the 1980s; but, even with over 40,000 seedlings planted since the year 2000, the success of reestablishment has been minimal. White-tailed deer pose a serious threat to restoring this conifer component to the landscape when deer densities are moderate to high. A two year study was conducted to evaluate the effectiveness of seedling age at time of planting and also compared several control methods to deter browsing. The results suggest that the one-year old seedlings planted were less susceptible to infestation to pine bark adelgids and experienced a higher survival rate than the two-year olds. Seedlings that were bud-capped, regardless of age, experienced significantly less browsing rates than those not bud-capped.

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Chapter I: Introduction

Restoration. Ecosystems of North America have undergone substantial changes since European settlement. Attempts to restore native ecosystems, from prairie to forest, are ongoing with resource managers and there are many challenges to be met. With an ever-increasing amount of land being converted for developmental and agricultural purposes it is imperative to protect, maintain, and restore areas where it is feasible. Fortunately, there is a considerable amount of land protected under various state, federal, and private entities. It is at these locations where managers are able to apply management techniques in an attempt to assure healthy and balanced communities.

When initiating a restoration project it is important to understand what the ecosystem was like under natural pre-settlement conditions, know what human-caused activities degraded the system, and ultimately determine the most appropriate approach to take to reach the desired goals. In addition to many of our current systems being degraded considerably there are constant new threats, including invasive species, which our native ecosystems never had encountered in the past. For this reason it is important to evaluate the current components and determine what is feasible.

In Minnesota, eastern white pines (*Pinus strobus*) were once a predominant component in the forests of the central and northern portions of the state. This component of the forest has experienced significant declines resulting from logging and associated fires, land clearance for agriculture and livestock, and finally a century of fire suppression. What was once a major forest component of the lake states (Minnesota, Michigan, and Wisconsin)

prior to the mid-1800s, the white pine forest type made up just 203,564 ha in the these states in the 1980s (Spencer, Leatherberry, & Hansen, 1992).

Reestablishing pine species throughout central and northern Minnesota has been a challenge with managers since restoration has become a priority. Currently there are many factors on a local scale inhibiting successful reestablishment including diseases, animals and environmental constraints. A full understanding of these various mechanisms, and how to address them, will enable restoration attempts to be successful.

Where white pines historically occurred we now frequently find many hardwood species. The loss of the conifer component has altered the species composition and overall forest productivity. It is of great importance to restore this component in forest ecosystems to improve habitat for the species which depend on it. In order to attempt this restoration there must be a thorough understanding of white pine ecology, history, importance, and threats.

Ecology of Eastern White Pine

Eastern white pines (*Pinus strobus*) are frequently found towering above the rest of the forest canopy throughout their geographic range. Compared to other species of pine, white pine is long lived with upper limits ranging from 380 to 426 years (Steams, 1992). The geographic range in North America extends throughout the northeastern portion of the United States and into southern Canada; Minnesota lies on the westernmost edge of this range. In Minnesota white pine grows well in both the Laurentian Mixed Forest province in the northeast and the Eastern Broadleaf province which runs in a band from the southeast section of the state to the northwest (Figure 1.1). White pine occurs in various successional stages;

including a pioneer after disturbance, a long-lived successional tree in mature or climax forests, and a fire-maintained climax type (Abrams, 2001).

Throughout its range it is a major species in five forest types recognized by the Society of American Foresters: White pine, white pine-hemlock (*Tsuga Canadensis*), white pine-northern red oak (*Quercus rubra*), white pine-chestnut oak (*Q. prinus*), and white pine-red pine (*P. resinosa*) (Burns & Honkala, 1990). It is also present to some degree in 23 others, showing its versatility (Steams, 1992). Historically white pine was not a dominant species at the regional level but was likely to occur in nearly pure stands in areas such as river and stream valleys, ridge tops, and glacial outwash (Abrams, 2001). It has been suggested that white pine may have been a climax dominant in the westernmost part of the range where hemlock was absent (Braun, 1950). The pre-settlement forest composition within the Laurentian Mixed Forest in northern Minnesota was: Jack pine (*Pinus banksiana*) (22%), aspen (*Populus spp.*) (21%), red pine (19%) and white pine (13%) (Spurr, 1954).

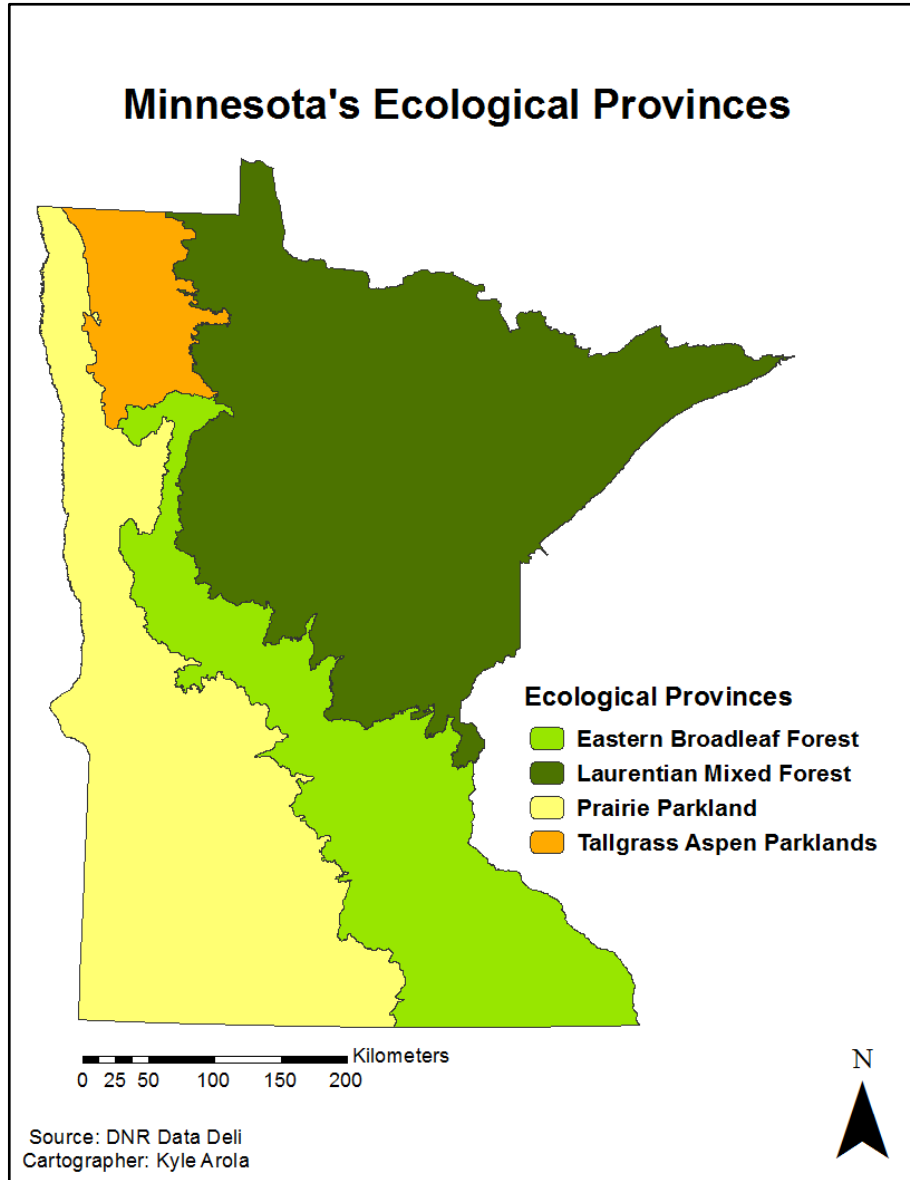


Figure 1.1. Distribution of Minnesota's biomes.

Critical stages in successful establishment of a tree include seed formation, germination, and early establishment. Other factors including light, water, nutrient availability, and form and structure of the root and stem will affect survival and growth (Steams, 1992). The growing season over much of the white pine range in North America is 90-180 days, being approximately 110-135 days in Minnesota (Wendel & Smith, 1990). The

majority of terminal growth occurs between late May and the first of July in Minnesota (Steams, 1992). White pine seedlings experience minimal growth during the first few years of life and may succumb to competition from herbaceous and woody associates; average annual height growth is approximately 40 centimeters (cm) once the tree reaches 10 to 20 years of age.

White pines begin to produce cones between 5 and 10 years of age but do not have significant production until 20 to 30 years old (Krugman & Jenkinson, 1974). Seeds are dispersed by the wind and can be carried 61 meters (m) in stands and up to 213 m in open areas (Wendel & Smith, 1990). Seeds are also dispersed by animals including gray squirrels (*Sciurus carolinensis*), white-footed mice (*Peromyscus leucopus*) and red-backed voles (*Clethrionomys gapperi*). These species all store seeds in caches, and if the animal fails to revisit the cache the seeds may germinate, providing environmental conditions are suitable (Abbott & Quink, 1970; Wendel & Smith, 1990). Favorable seedbeds include moist mineral soil, mosses, and short grass cover of light to medium density. Dry mineral soil, pine litter, lichen, and very thin or very thick grass covers are poor seedbeds in full light but are adequate in shade (Horton & Bedell, 1960; Wendel & Smith, 1990). Seedlings commonly become established post fire or blow down as light availability increases following these events (Abrams, 2001).

Classified as being moderately fire resistant, mature trees are able to survive most surface fires due to thick bark, absence of branches near base, a moderately deep rooting system, and needles which possess a resin content which reduces their flammability (Abrams, 2001). Under natural conditions white pine is most abundant in forests with a rotation period

of 150 to 300 years between catastrophic fires. Following a fire or blow down, white pine seedling establishment occurs slowly over a period of 20 to 40 years (Frelich, 1992).

Although the mature trees are moderately fire resistant, saplings and seedlings may succumb to high-intensity fires.

White pines are intolerant of extended periods of drought and high temperatures and are considered to have intermediate establishment success in shade-suppressed locations. Although suppressed in heavy shade white pine is more tolerant than both red and jack pine, requiring a minimum of just 20% full light for survival (Ahlgren, 1976; Torbert, Tuladhar, Burger, & Bell, 1988). Maximum growth rates are achieved in 45% of full light. Ward and Mervosh (2008) found that seedlings grown under a closed canopy averaged 130 cm after 9 years, which was the average height of seedlings grown in open sites after just 3 years. Seedling increase in biomass was found to be no longer limited in 50% full light in Ontario, Canada and seedlings did not show any difference in total growth where exposure was greater than 50% full light (Wetzel & Burgess, 2001).

A study conducted in northwestern Connecticut revealed that saplings grown in the understory among eight hardwood species had 65% survival over a 5-year period (Abrams, 2001). A 59% survival rate over a period of 19 years was recorded in white pines grown under a mixed species canopy in Massachusetts (Lorimer, 1983). Height and diameter growth response of eastern white pine to partial hardwood overstory release was recorded at Camp Ripley Military Reservation in Crow Wing County, Minnesota. The results indicated that height and diameter growth in seedlings experiencing overstory release was significantly

higher than in those not experiencing overstory release, with height growth increasing 42% following release (Puettmann & Saunders, 2000).

In addition to the amount of light reaching the forest floor, the composition of the species in the overstory also influence white pine survival and recruitment. Several authors have shown that aspen frequently become established in dense stands and therefore may suppress white pine seedlings (Petersen & Squiers, 1995; Pinno, Lieffers, & Stadt, 2001). Additionally, Cornett, Puettmann, and Reich (1998) found that under a conifer canopy white pine had a higher mortality rate than those under a deciduous canopy.

There is typically an increase in herbaceous competition with decreased overstory cover due to more sunlight reaching ground level. Herbaceous competition can result in reduced survival and growth rates in seedlings by reducing the availability of moisture, light and nutrients (Stiell, 1985). The competing vegetation can also influence survival and growth of the seedlings by limiting photosynthetically active radiation (Brand & Janas, 1988). However, herbaceous competition has been shown to provide protection from browsing (Saunders & Puettmann, 1995), white pine blister rust (Krueger & Puettmann, 2004), pine bark adelgids (Krueger & Puettmann, 2004), and reduce terminal shoot damage from white pine weevil (Pitt, Morneault, Parker, Stinson, & Lanteigne, 2009).

White Pine Role in Industry, Forest and Wildlife

The forests of North America have held different roles throughout the past several hundred years from the human perspective. When North American harvest of timber began in the 1700s the forest was seen as a positive resource, especially the white pine forest. White pine became one of the most valuable renewable resources because of its abundance and

multitude of uses. The demand for timber increased dramatically with westward expansion as its products were readily used in the manufacturing of homes, ships, furniture, and railroad ties.

As the vast forests of the eastern United States began to disappear the logging industry entered the Great Lakes region and became established in the 1800s. During this period the resources of the forests were thought to be infinite, but as the clearing continued it quickly became recognized that this was not the case (Williams, 1992).

The role of the forest took on an aesthetic appreciation early in the 20th century as people began to appreciate the forest and wild places. Writers such as Emerson and Thoreau contributed to this appreciation as they wrote about nature, producing a higher awareness and respect for it. People now had a desire to preserve and restore the forest for future generations. Federal forests were created to ensure a supply of timber and to set aside areas for recreational purposes. Later on some of these areas would be preserved as “wilderness” areas and in Minnesota this would include the Boundary Waters Canoe Area Wilderness (BWCAW).

In addition to industry, white pines also have an important role in regards to wildlife. They provide nesting habitat for several bird species; bald eagles (*Haliaeetus leucocephalus*) and ospreys (*Pandion haliaetus*) build nests on main branches near the crown trees (Mathisen, 1968). Within the Superior National Forest, Minnesota nest survey data collected over 31 years indicated that white pines held 81% of total bald eagle nests and 77% of osprey nests (Mathisen, 1968).

Although black bears (*Ursus americanus*) avoid white pine dominated communities, research indicates that during April and May in northeastern Minnesota sows and their cubs

spend more than 95% of their time within 180 m of either an eastern white pine or an eastern hemlock with a diameter at breast height (DBH) greater than 50 cm (Rogers, Wilker, & Scott, 1990). Black bear sows commonly leave their cubs at mature white pines while they forage nearby in non-pine forest communities (Elowe & Dodge, 1989), here the cubs are able to quickly climb the tree to escape from predators. Additionally, white pines also provide den sites for black bears due to their large diameters and, with the outer bark being moderately decay-resistant (Hosie, 1969), have a tendency to become hollow (White, 1953).

In addition to providing valuable habitat to wildlife white pines also serve as a source of food to many others. The seeds provide nutrition to numerous songbirds and small mammals, while the foliage is browsed by snowshoe hares (*Lepus americanus*), white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), and cottontail rabbits (*Sylvilagus floridanus*) (Wendel & Smith, 1990). The roots of seedlings and saplings are browsed by pocket gophers (*Geomys bursarius*) and the bark is foraged on by several mammals, including porcupines (*Erethizon dorsatum*) (Huntly & Inouye, 1988).

White Pine Mortality

Common sources. There are a known 110 disease organisms and 277 insects that attack white pine (Wendel & Smith, 1990). Of these, only seven diseases and 16 insects cause sufficient injury or mortality to be of concern. Between 1990 and 2002, 110 out of 167 red and jack pine plantations in northern Minnesota failed due to several of these factors (failing was defined as requiring additional plantings for regeneration) (MNDNR, 2007). It is important to consider these threats and if a single one is present on the landscape the question

arises whether the restoration is justified due to the time, money and resources that will need to be invested.

White pine causes of death on a local scale within the lake states (Minnesota, Wisconsin, and Michigan) were identified for 44% of the white pines that experienced mortality in recent stand inventories. Mortality was attributed to disease (57%), weather (26%), animals (12%), fire (3%), and suppression (2%) (Spencer et al., 1992). The diseases were determined to be principally white pine blister rust and general classes of stem decay diseases.

White pine blister rust. White pine blister rust (*Cronartium ribicola*) is a major threat to all five-needle pines, especially eastern white pine. White pine blister rust (WPBR) is a fungus that produces main-stem and branch cankers that can ultimately result in mortality in any part of the tree post the site of infection (i.e., if the base of a branch becomes infected near the stem the entire branch may die). It produces five types of spores and requires two hosts alternating between gooseberries (*Ribes* L) and five-needle pine species, but interestingly cannot spread from pine to pine. WPBR was introduced to North America from Europe through shipments of infected containerized seedlings and first discovered in New York in 1906 (Ostry, 2000); it is believed to have arrived in Minnesota around 1916 (Sauerman, 1992).

Sauerman (1992) found that in northern Minnesota younger trees had a greater frequency of WPBR infection: 83% of the branch cankers and 81% of the stem cankers observed were in trees less than 12 years old. WPBR was suspected to have culled out significant numbers of trees as the plantations aged. Based on current knowledge it is unclear

if blister rust acts simply as a thinning mechanism or if overtime it will lead to total stand elimination (Jones, 1992).

There are several precautions to take in order to reduce WPBR to acceptable levels including performing microsite evaluations to avoid planting in high risk areas, planting below a closed canopy, and avoiding planting in small openings (Anderson, 1973; Sauerma, 1992). It can be argued that with the low incidence rate of blister rust that Sauerma found in his survey, 5% of total trees infected, that the expense associated with WPBR control practices may not be justified.

White pine weevil. White pine weevil (*Pissodes strobe*) is a native insect that is considered one of the most destructive pests for white pine. The weevil appears to target trees exposed direct sunlight and that are greater than 3 feet in height but less than 20 feet (Hoover, 2011). The terminal leader is attacked and typically will die due to the larvae beneath the bark feeding within the cambium layer. The weevils will rarely cause mortality in healthy white pines, but by killing the terminal leader the tree typically loses 2 or more years in height growth and deformations may also result (Wallace & Sullivan, 1985).

Sauerma (1992) surveyed 126 white pine plantations in Minnesota and reported that 9% of the total trees and 23% of the stands showed weevil damage. An effective management practice to prevent weevil damage is to plant seedlings beneath a closed canopy due to the weevil's preference for trees in full sunlight (Houseweart & Knight, 1986). There is a tradeoff for planting in the understory; white pines generally grow slower and in dense shade may experience mortality (Wendel & Smith 1990).

White-tailed deer. Deer have the potential to alter the composition of forests due to the food sources they select. They directly affect forest communities through browsing, which involves above ground feeding on twigs, shoots, leaves, needles, buds, or flowers (Dannell, 2003). Browsing can sometimes lead to the elimination of a species from particular stands, especially when populations of the animals are high and the target plants are uncommon (Alverson, Waller, & Solheim, 1988).

In regards to conifers, browsing may stunt the growth of seedlings, ultimately affecting regeneration (Whitney, 1984). Sauerman (1992) stated that deer are the most important serious damaging agent to white pine in Minnesota. A study conducted in white pine plantations within the Chippewa and Superior National Forests, Minnesota found repeated deer browse injury to be the greatest limiting factor in plantation establishment and stated that the general condition of most plantations is poor to fair; the authors stated that once the white pines reached nine feet tall or had been planted for 11 years deer damage decreases (Sauerman, 1992). In order for the trees to reach this size and/or age it may be necessary to implement controls to prevent the damage where populations are high.

A survey completed by resource managers responsible for pine restorations throughout northern Minnesota indicated that 73% of the respondents stated that browse mortality associated with deer had a strong effect on regeneration (Palik & Johnson, 2007). Several factors contribute to the effects deer have on seedlings including densities of deer and seedlings, seedling size, quality and abundance of alternative food, ability of deer to find seedlings, nutrient content, hiding cover, and amount of edge (Reimoser, 2003). In general, the negative impact on vegetation increases as deer densities increase.

During winter months in north-temperate regions white-tailed deer food sources become limited. In order to meet their energy requirements they consume woody browse (Mautz, 1978) and catabolize fat and protein reserves which were stored during the summer and fall months when there was greater food availability (Delgiudice, Mech, & Seal, 1990). White pine is an intermediate food source preference to white-tailed deer (Fashingbauer & Moyle, 1963) and is most commonly browsed in late winter when more favorable food sources have been depleted and reserves diminished (Rogers, Mooty, & Dawson, 1981). Furthermore, if it is a year with minimal snowfall accumulations the terminal buds of the seedlings may remain above the snow's surface and therefore have an increased risk of being browsed throughout the winter. It is typical that diets of a healthy deer population will contain 2-4% white pine when other preferred food sources are present, but where deer populations are high and other food sources have been depleted white pine can make up to 50% of the diet (Rogers et al., 1981).

Within 1 year on a site in northern Minnesota 38% of white pine seedlings showed signs of browse damage, with 17% of the total browsed exhibiting terminal leader damage (Saunders & Puettmann, 1995). There were some preventative measures taken to deter browsing and it was anticipated the browsing rates would have been higher had there not been. The authors noted that deer often selected seedlings that had been previously browsed over seedlings that had not been.

When deer browse white pine seedlings they tend to primarily target the current annual twigs and needles of the terminal leader, avoiding lateral shoots (Hay & Rennie,

1989). If the terminal shoot is browsed during the growing season, one or more adventitious buds form new shoots which then assume terminal positions (Hay & Rennie, 1989).

For reasons as yet unknown, moose and deer seem to browse more heavily on pines in plantations than in natural stands (Peek, Urich, & Mackie, 1976). Browsing by deer at Itasca State Park in Minnesota curtails recruitment of both white pine and red pine into the overstory in both plantations and natural stands (Ross, Bray, & Marshall, 1970). Browsing in plantations is heaviest along the perimeter adjacent to cover and along travel corridors through plantations (Hay & Rennie, 1989).

In addition to browsing, deer may have a negative effect on young white pines through trampling. Repeated events damage the tissue of the tree making more likely to succumb to death. Also, in the fall male deer rub their antlers up and down the stem of trees to rid the velvet that is present on them, mark territory, or to leave scent. This action damages the cambium, which is critical in the transportation of nutrients and water throughout the tree (Figure 1.2).



Figure 1.2. Damage associated with male deer rubbing antlers.

Other mammalian threats. While deer may pose the greatest threat to white pines through mammalian herbivory, there are additional species that impact white pines including browsing from rodents and hares and damage from black bears. Terminal buds on seedlings and saplings are browsed by hares (Pastor, 1992); it can be distinguished whether a hare or deer browsed the tree. Hares bite the seedlings between their upper and lower incisors leaving the top will at a clean 45 degree angle whereas deer leave the browsed portion horizontal and ragged (Pastor, 1992).

Mice and voles feed on the cambium layer at the base of the tree; when there is snow cover or dense vegetation these species may feed more on the trees due to protection from

predators. Additionally, voles may sever the stem of small trees and will also feed on roots (Gill, 1992). Porcupines girdle the tops of larger trees near the crown (Jones, 1992).

White pine and browsing. Reasons for conifers not being a preferred food source for many mammals are due to the leaf, stem, and bark tissues being difficult to digest (Bryant & Kuropat, 1980). Conifers have high concentrations of resins and lignins which prevent water loss and these are what make needles difficult to digest and also reduce the nutritional value (Bryant et al., 1991). The needles also have high concentrations of secondary compounds, including monoterpenes and pinosylvan, whose sole function appear to deter browsing by making the tissues unpalatable or even toxic (Bryant et al., 1991). Browsing on seedlings less than three years old has been shown to be slight, but more intense on older seedlings (Hay & Rennie 1989), indicating possible ontological changes in palatability.

In addition to having a variety of chemical defenses to deter browsing, many plant species have evolved the ability to increase reproduction and/or growth following herbivory (Dyer, 1975). The ability of the plant to recover and allocate energy towards increased growth is termed compensatory growth. Previous studies on compensatory growth have shown the degree of compensation to be influenced by season of herbivory and the level of competition the plant is experiencing (Maschinski & Whitman, 1989). In general, plants experiencing herbivory early in the growing season with minimal inter- and intraspecific competition will experience greater compensatory growth than those experiencing herbivory later in the growing season and in areas with increased competition.

Puettmann and Sanders (2001) measured the response of biomass growth, relative height and diameter growth, and final total biomass of seedlings following different clipping

(mimicking herbivory) intensities after one growing season in white pine seedlings grown at various levels of interspecific competition. The authors discovered that seedlings experienced a decline in biomass growth, relative diameter growth, and final total biomass, but did experience an increase in relative height growth at low clipping intensities. Here the authors suggest that rather than being a response to herbivory, the height growth may be an adaptation for competitive ability.

Browsing on conifers generally has a more detrimental effect than it does on deciduous trees (Saunders & Puettmann, 1995). Reasons for this include that when needles are removed from conifers the nitrogen they contain is removed and not available for growth. Secondly species such as white pine have deterministic growth from terminal leaders, in their case these are whorled branches arranged vertically; deciduous trees exhibit indeterminate growth; whereas, there are many shoots throughout the tree and in the event a browse occurrence there is new growth readily available which is not the case of white pines (Dannell, 2003). Finally, browsing causes the seedling to allocate carbon to repair rather than grow (Kimmins, 1996); continual injury from browsing with the inability to grow out of browse height ultimately may lead to decreased survival rates (Aldous, 1939).

The probability of mortality from herbivory seems likely to be correlated to tree size (total height and stem diameter). In theory, it would be expected that as the tree grows larger the likelihood from experiencing mortality from a single herbivory event decreases. Additionally, larger trees may succumb when experiencing greater herbivory intensity (defined as number of herbivory events on the individual tree).

Mille Lacs Kathio State Park

Mille Lacs Kathio State Park (referred to as Kathio hereafter) is located in Mille Lacs County in central Minnesota along the southwest shore of Lake Mille Lacs; the second largest lake within the state. Within the park's boundary is the Rum River, the only outlet of Lake Mille Lacs, which flows through Lakes Ogechie, Shakopee, and Onamia then south to the Mississippi River. Kathio's location comprises North and South Kathio Townships within the county. Kathio is Minnesota's fourth largest park at 4,276 hectares. The park lies in close proximity to the Laurentian Mixed Forest and Eastern Broadleaf Forest transition zone, which leads to great diversity in the flora and fauna of the park.

The landscape was formed by glaciers of the most recent ice age during the Nebraskan, Kansan, Illinoian, and Wisconsin periods. These periods were separated by fluctuations in temperature which resulted in the glaciers advancing and retreating. Between the warming and cooling phases glacial till was deposited in the area; Kathio lies on an end moraine.

The region has been a mixed conifer forest since 1300 BC. Prior to this time it appears that the landscape was dominated by northern hardwoods and oak savannahs. The period from approximately 1450 AD to 1850 AD was marked by cooler, wetter conditions and occasional droughts; this climate resulted in white pine becoming established in its current geographic range (Bryson & Murray, 1977). In addition to the climate, major fires during this time helped form extensive stands of white pine. White pines became established in northeast Minnesota approximately 7000 years ago. Pollen samples collected from nearby Black Bass and Ogechie lakes within Kathio indicate white pines became present on the landscape 3300 years ago.

Currently Kathio is a second-growth forest consisting of aspen, birch, maple, oak, and other northern hardwoods. Wetlands are abundant in the eskers on which the park is located. A few isolated remnant stands of conifers provide diversity to the landscape and a hint of what the forest looked like a century ago. Mature white pines are present but natural regeneration is minimal presumably due to a combination of the abundance of deer and the overall lack of mature seed trees.

Logging in the Mille Lacs region. Logging in Minnesota began in the St. Croix River valley in 1837. In 1847 Franklin Steele, a lumber mill owner, sent Daniel Stanchfield to search for pine along the headwaters of the Rum River. “On this voyage Stanchfield found that from the point of present day Princeton to the mouth of Mille Lacs lay fabulous stands of white pine” (Drews & Brixius, 1998); Stanchfield stated that the Mille Lacs region could not be logged by 70 mills in 70 years. In 1850, shortly after Stanchfield visited, logging camps were established in the Kathio region. The Rum and West Branch Rivers were cleared in order to transport logs downstream to sawmills along the Mississippi River. These camps quickly cleared the area of timber and following logging operations in the 1850s and ‘60s the government closed Mille Lacs to logging and would not be open again for additional logging until 1896. Prior to logging operations spreading north of Onamia in the 1890s the area was dominated by white pines up to within a quarter of a mile of Mille Lacs Lake, the shoreline of the lake consisted of hardwood species including maple, oak, and elm (Rogers, 1958).

Along with having an abundant supply of majestic white pines, the area was ideal for early logging companies with the close proximity of Mille Lacs Lake and the Rum River. Timbers harvested in the Kathio region were hauled out onto the frozen lake or Rum River

with large sleds and were floated to mills in Minneapolis and St. Anthony (Rogers, 1958). By the time spring came some of the smaller lakes were practically covered with logs. Since multiple companies logged in the area logs were branded to be identified later upon arrival at sawmills.

The majority of the south shore of Mille Lacs and area around Lake Onamia was logged by the Foley Bean Lumber Company. Most of the large companies disappeared by the early 1900s (Onamia–1900-1976, 1976). Following these companies were smaller crews that came in for the leftovers of the area, which was primarily pulpwood that was obtained from the leftover hardwoods. Companies along the northeast side of Mille Lacs constructed a rail line in 1912 to connect to the Soo Line that ran through Onamia. This helped transport logs out of areas that were too far from waterways. After their work ended in the 1920s the land was practically cleared of all timber.

Post-logging regeneration of conifers was minimal due to the lack of mature seed trees and many seedlings and saplings were destroyed by fires associated with slash leftover from logging (Nowacki & Abrams, 1992). In addition to the lack of seed trees, browsing associated with increased deer densities resulted in seedling mortality following repeated browsing events.

Restoration at Kathio. State parks in Minnesota have long-term management plans in place to achieve desired management goals. Kathio's management plan states that the vegetation in the park has undergone many minor changes over the past 200 years; the single major difference is the current absence of the conifer forest, particularly the white pine component (MNDNR, 1980). Prior to being logged the region was identified as having white

pine stands mixed with red pine and hardwoods (oak, maple, basswood, and ash). Northward expansion of the logging industry and settlement created suitable edge habitat in the Kathio region and with the extirpation of the apex predator gray wolves (*Canis lupus*), deer were now able to inhabit the region at historically high densities.

Currently at Kathio there is a lack of seed trees and minimal natural regeneration. Park staff has been planting both bare-root and containerized seedlings with goals of restoring the conifer component of the forest. Detailed records have been kept since 2000 and there have been over 40,500 seedlings planted within the park. The majority of these seedlings appear to be unable to achieve a sufficient size to not be adversely affected by deer browsing. Seedlings that are successful typically have some level of control measure to deter browsing.

Control options at Kathio. Since deer are suspected to be the primary hindrance in restoration attempts at Kathio, quantifying the extent of their damage and understanding the effectiveness of various control measures is a primary concern. Some type of deer control measures must be implemented if plantations are to succeed where deer densities are high (Mielke, Collyard, & O'Brien, 1989). As stated earlier, white pine seedlings are of an intermediate preference to deer; if there is an abundant supply of preferred food sources the deer will unlikely target white pines. However, if preferred food sources are scarce and deer densities are high they are likely to browse the white pines, especially in the winter and spring.

Bud-capping. Currently the most commonly used control method at Kathio is to use physical barriers to discourage deer browsing. Bud-capping is a technique that focuses on protecting new growth on the seedling, typically the apical terminal leader. This method

involves folding a piece of paper in half and stapling it on the terminal leader. Bud-caps should be applied each fall until the tree is tall enough, approximately 1.5 meters, to escape adverse effects from browsing.

Seedlings protected by paper barriers may face mortality on dry, hot sites due to heat or water loss (DeYoe, deCalestra, & Schaap, 1985). This is especially true if the terminal leader fails to grow beyond the bud-cap in the spring. Ward and Mervosh (2008) observed distorted top growth on white pine seedlings in their study attributed to the terminal leaders snagging on the bud-caps; to minimize this risk, bud-caps in the future were placed slightly below the top of the terminal leader. Bud-capping is relatively inexpensive but can be time consuming where there are a lot of seedlings to be protected. Bud-capping has shown no signs of limiting growth but there is the potential to bend and break the terminal leaders in strong winds (Duddles & Edge, 1999).

Wire caging. Another physical barrier involves placing a wire cage around the entire tree to eliminate any chance of browsing. This method has several advantages over bud-capping. First, unless the cage is knocked over by wind or some other force, it will protect the seedlings until they reach the height necessary to escape browsing, which results in less frequent visits to the site to protect the seedlings. Secondly, since the cages are constructed from metal they have a long life and can be used to protect multiple cohorts. Lastly, unlike bud-capping, they do not produce an environment making the seedling susceptible to heat stress or water loss. Although this method is very effective it can become costly when protecting a large number of seedlings and it can be difficult to remove cages when lateral branches have grown through the spacings of the cage.

Chemical deterrents. There are a variety of chemical deterrents available; chemical deterrents make the tree less palatable either by taste or smell repellants. These are usually temporary fixes and typically need to be reapplied every few months to successfully prevent browsing, causing additional staff time due to frequent visits to the site. Kathio has used Plantskydd in the past, a deterrent which produces a scent deer associate with predators, but the results were not satisfactory and use was discontinued in 2007 (Kris Erickson, personal communication, August 10, 2011). Currently chemical deterrents are not being used at the park.

A study involving Douglas-fir (*Pseudotsuga menziesii*) and browsing by black-tailed deer (*Odocoileus hemionus columbianus*) found no significant differences in browse frequency over two years, or survival over five years, among browse-deterrents including bud-capping, tubes, netting, leader guards, and Deer Away repellant (Gourly, Vomocil, & Newton, 1990). This suggests that utilizing an inexpensive alternative may be effective, especially under financial constraints. In a separate unpublished study the authors found bud-capping to be ineffective (0-6% of the total seedlings protected) where deer densities were estimated to be 18 or more deer per square mile. However, bud-capping was found to be effective, protecting 97% of the bud-capped seedlings, where deer densities were 12 or fewer per square mile (MNDNR, 2007).

Deer management. Another method that had not been used in Kathio's history, until November 2012, was the control of the white-tailed deer population. Not only at Kathio, but throughout the entire Great Lakes Region deer populations are at a historic high. This is in part due to the logging era that created openings and edge habitat that deer depend on. Once

the deer reached these northern regions they often made many restoration attempts difficult through their repeated browsing on seedlings. With Kathio being a state park the deer serve as an aesthetic appreciation to the public and people tend to be against the idea of having special hunts in state park boundaries.

Hypotheses

Deer thrive in edge habitats which represent areas of diversity and at Kathio openings created by the primary road transecting the park create an increased diversity of flora compared to the forest interior. The majority of the park is dominated by mature hardwood species and these trees compete for light in the canopy and minimal sunlight is available for understory plants. However, the roads in the park provide openings where sunlight can reach the forest floor and allow herbaceous plants to flourish. Deer are attracted to these areas of abundant food sources and appear to congregate along the road edges.

There may be an association between 1- and 2-year-old seedlings and browsing rates. With 2-year-old seedlings being larger and potentially more nutritious, they may be sought out more than the smaller 1-year-olds. In addition, 2-year-olds may simply be more accessible during winter months when snow cover is sufficient to cover the shorter 1-year-olds. Over the long-term, by planting larger seedlings they may be able to recover more quickly from browse incidences and escape browse level heights sooner.

This experiment compares three different factors leading to seedling establishment. Those factors include seedling age, distance from road (near vs. far), and presence/absence of bud caps. Plots located near road are expected to experience increased browsing pressure due to their proximity to the road, whereas bud capped seedlings will experience decreased

browsing. Two-year-old seedlings are expected to experience greater browse events than 1-year-old seedlings. One-year-old (containerized) seedlings are hypothesized experience higher survival rates than 2-year-old (bare-root) seedlings due to their roots establishing earlier post-planting. In regards to survival rates, 1-year-olds are hypothesized to have higher rates than 2-year-olds due to their root systems becoming established earlier than the 2-year-olds.

In an attempt to understand seedling response following release from herbivory I examined caged vs. uncaged seedlings. Seedlings enclosed within a wire cage are hypothesized to experience greater survival and growth rates over those not caged.

Chapter II: Materials and Methods

Site description. The experiment was conducted within Mille Lacs Kathio State Park, located approximately 7.5 km northwest of Onamia, Minnesota, in northern Mille Lacs County at approximately 46°E 7' N, 93°E 44' W (Figure 2.1). The 4,276 ha park lies on an end moraine which resulted from glaciers approximately 10,000 years ago. The soil types of Kathio are predominately Duluth and Sanburn which are associated with moraines and end moraines (USDA, 2012). These are well drained soils with typical profiles of fine, sandy loam to depths of 38 to 49 centimeters.

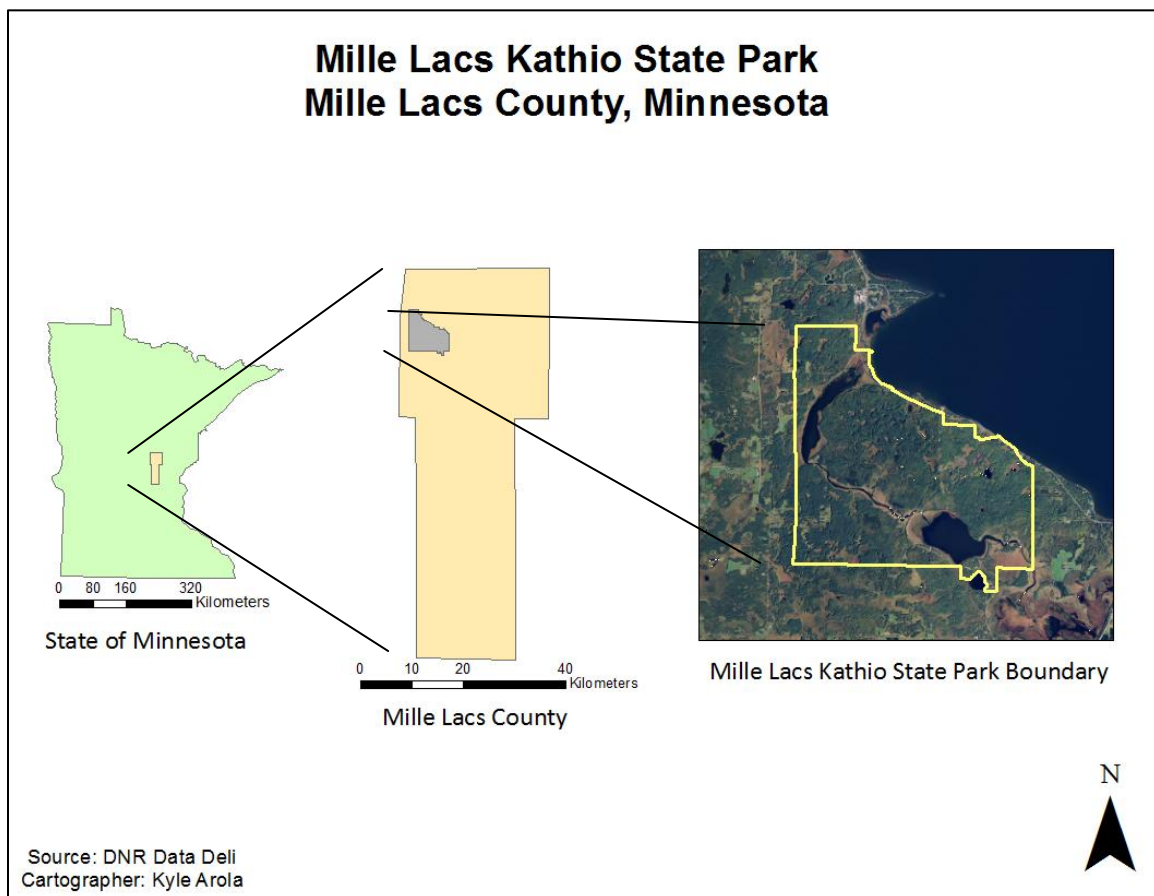


Figure 2.1. Mille Lacs Kathio State Park.

The climate of the region is mid-continental, with an average annual air temperature 4 to 7°C. Average cumulative growing season (April to August) rainfall from 1954 to present is 44.42 cm (Isle, MN station, Minnesota Climatology Working Group).

Experimental design. Geographic information systems (GIS) software was used to determine the locations where white pine seedlings would be planted at Kathio. Figure 2.2 shows the locations of eight separate 1/4 ha plots; each plot contains 100 (10 rows x 10 seedling/rows) seedlings. Seedlings were planted at 5.0-m intervals to assure adequate space for growth and to reduce the need for future white pine thinning operations. Summer orthophotos were analyzed and plot locations were selected so that seedlings would be planted under a deciduous canopy. In addition, stand basal areas (SBA) were calculated for existing trees growing in each plot; this method enables forest managers to calculate tree volumes and manage density of stands and competition. This resulted in all seedlings in seven of the eight plots being planted under a closed canopy with SBA values ranging from 33.12-68.06 m²/ha; one plot is of an intermediate canopy condition with a SBA of 16.08 m²/ha. Elevation throughout the park was identified in order to avoid planting seedlings along gradients where sunlight exposure and other factors would be unequal across plots.

Experimental plots. Plots were located along the primary road that runs through the park (Figure 2.2), in sets of two with one plot's edge 30-m (near) and the other plot 500-m (far) from the edge of the road (Figure 2.3). The 100 seedlings in each plot were planted according to four treatments: 1-year-old unprotected controls (Group 1a), 1-year-old bud-capped (1b), 2-year-old unprotected controls (2a), and 2-year-old bud-capped (2b). Bud-capping (Figure 2.4) involves placing a paper barrier on the terminal leader of the seedling to

deter mammalian herbivory, specifically that associated with white-tailed deer. Seedlings in the four groups were planted in a randomized block design to control for local soil variation. Random numbers were generated in Microsoft Excel to select the locations of the four seedlings within each block (Figure 2.5).

In addition to the eight experimental plots described above, a supplementary site with existing seedlings (both natural and hand-planted) were monitored in an area approximately a 1/3 kilometer south of the park office (Figure 2.2). These trees were last visited in 2007 as part of a separate study and planting at this site has not taken place since 2004. Browse damage appeared to be extensive at this location from white-tailed deer. In October 2011 I enclosed 50 seedlings with wire cages and flagged an additional 50 seedlings.

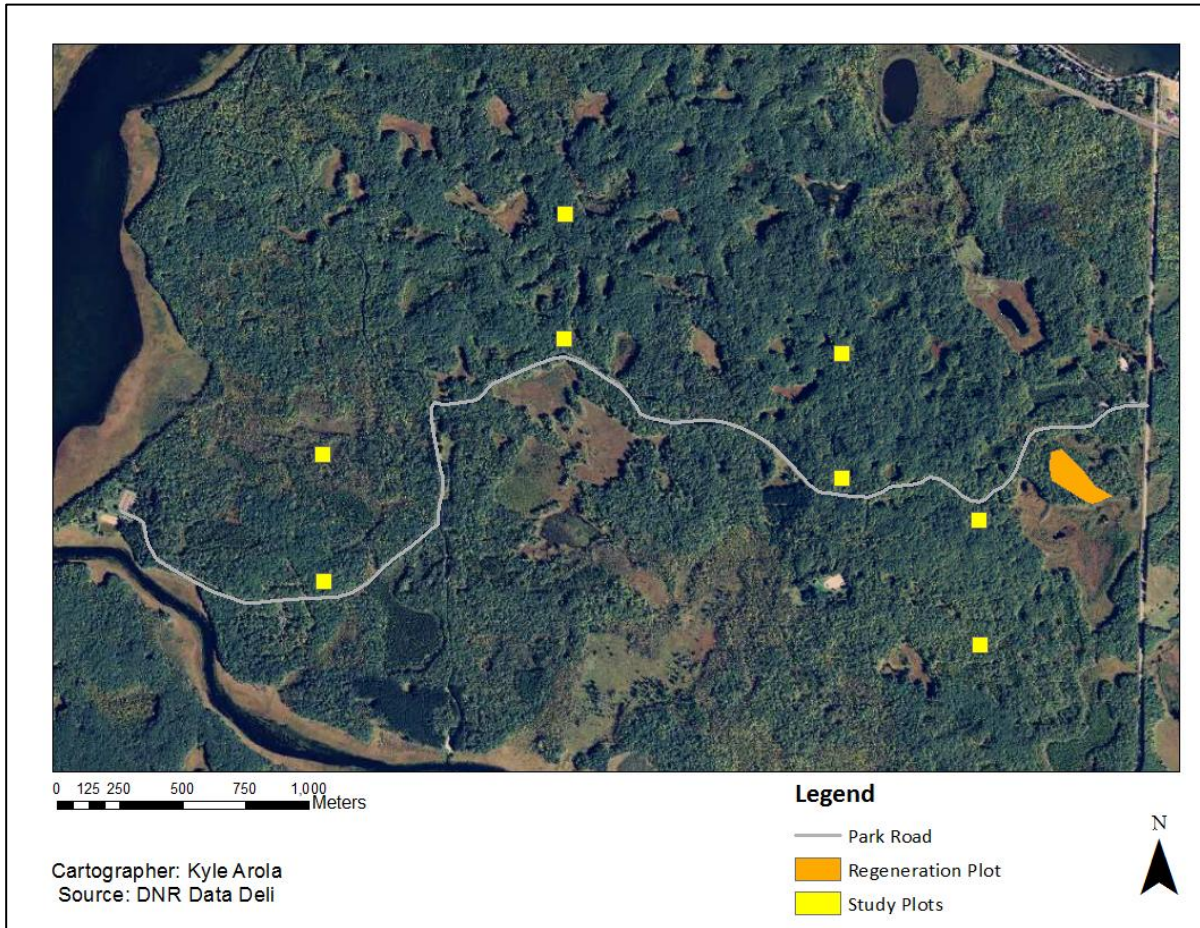


Figure 2.2. Study sites within Mille Lacs Kathio State Park.

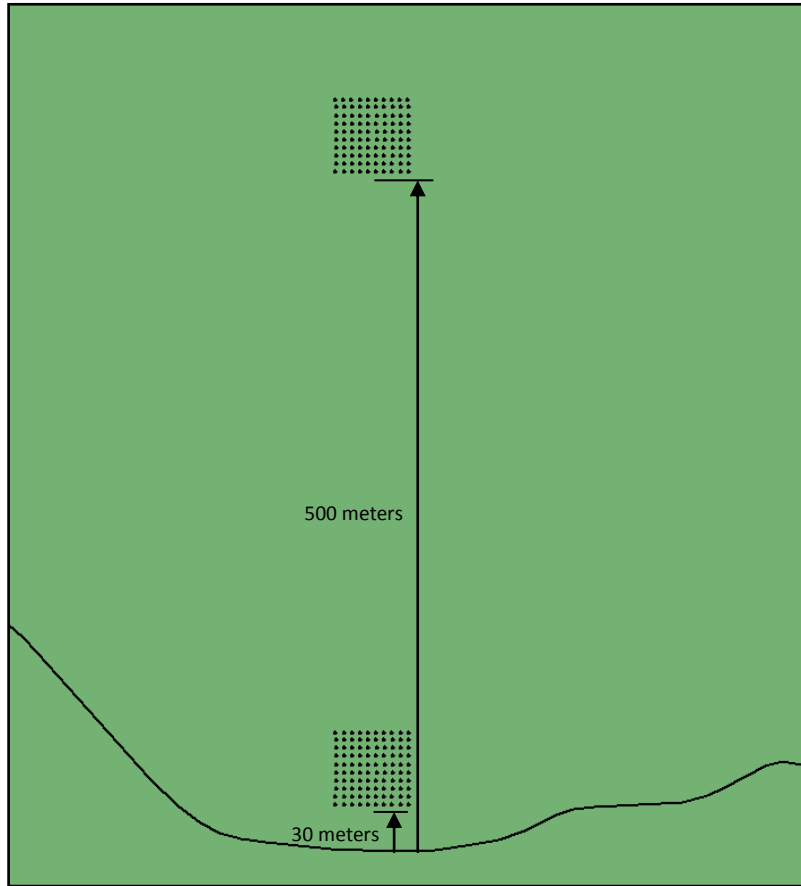


Figure 2.3. Set of two plots located 30 and 500 meters from road edge.



Figure 2.4. Two-year-old seedling with presence of bud-cap.

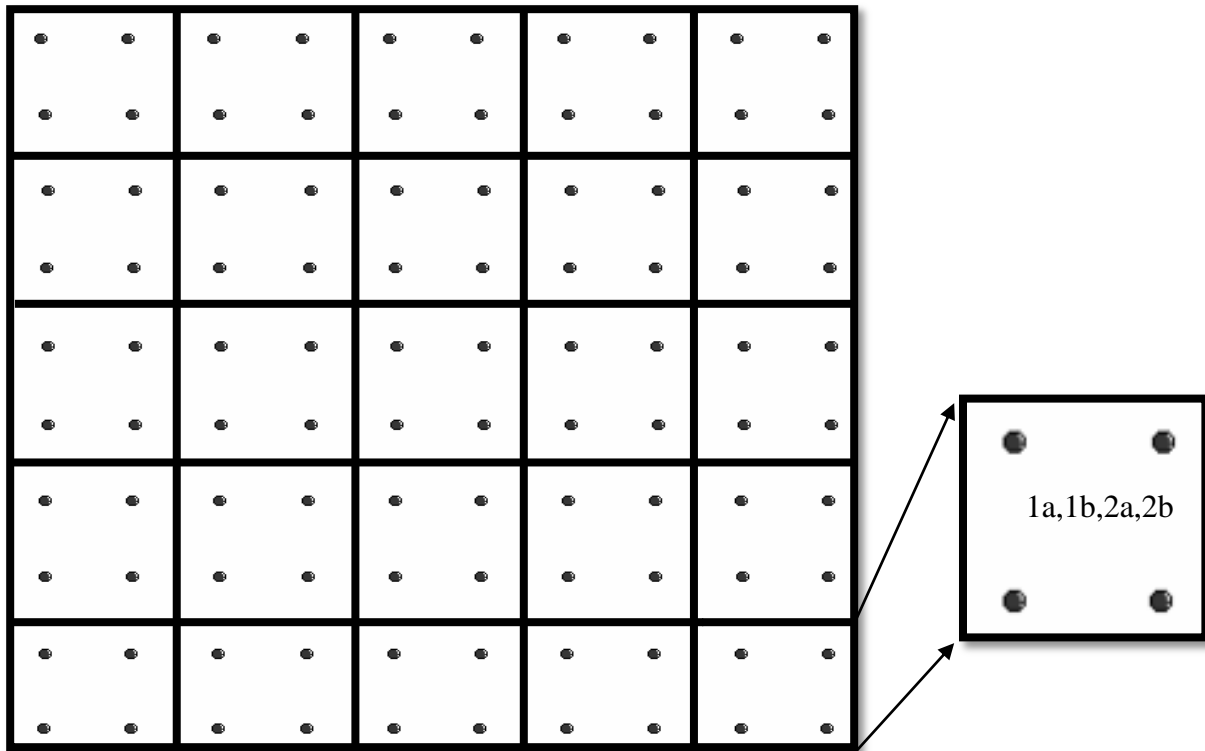


Figure 2.5. Division of each plot using random assignment in each section.

Field procedures. In early May 2011 I planted the eight experimental plots of 100 seedlings over a 3-day period. The 400 one-year-old seedlings were previously containerized, and the 400 two-year-old seedlings were initially bare-root. Figure 2.6 shows a size comparison of containerized and bare-root seedlings. Coordinates associated with the points in each plot were loaded into a GPS unit. The GPS unit was used to navigate to the southwest corner of each plot and from there I manually measured distances of 5.0 m intervals and placed a flag at each point indicating which seedling type to be planted. A container seedling dibble and speedy dibble were used to plant the one and two-year old seedlings, respectively.



Figure 2.6. One-year-old containerized (left) and 2-year-old bare-root (right) seedlings.

Measurements of total height (ground level to the top of the tallest bud) to the nearest 0.25-cm were recorded in May, July, and September of 2011 and 2012. Plots were visited in June, August, and October of 2011 and 2012 to record the status of the seedlings. A status score of 0-4 was assigned to each seedling as follows: 0) Seedling experienced mortality, 1) seedling has 25% or less green (healthy) needles, 2) 26-50% healthy needles, 3) 51-75% healthy needles, and 4) 76-100% healthy needles. Seedlings receiving a score of 0 were dropped from the study and the source of mortality was recorded when possible. Additionally, every other month beginning May 2011 seedlings were surveyed for browse occurrences.

Paper bud-caps (10x15cm) were placed on seedlings in groups 1b and 2b in October 2011, and again in October 2012. The bud-cap was placed on the seedling so that the top of the terminal leader was just below the top edge of the bud-cap, and folded around the terminal

leader and attached using three staples. Bud-caps were removed when seedling heights were recorded in May 2012 as they can minimize terminal growth in summer, and browsing of white pines throughout this time of year is minimal (Rogers et al., 1981).

SBA was calculated for each plot and this is estimated by measuring each individual tree's basal area (BA); which is diameter at breast height (DBH) in centimeters measured 1.37 meters from ground level on the uphill side of the tree. Each tree ≥ 3 cm DBH was measured in the northwest quarter (25 x 25-m) of each plot, an area representing 1/16th ha. The following equations were adapted from Glover and Barlow (2009) to estimate individual tree BA in square meters the following equation was used:

$$BA = 0.00007854 \times DBH^2$$

To determine the SBA per ha the following equation was used:

$$SBA = \frac{\sum_{i=1}^n BA_i}{A}$$

where BA_i is the basal area per tree for the i th tree and A is the area of the stand where BA was measured (in this case 1/16).

In early October 2011 100 randomly selected seedlings were flagged and their heights recorded at the supplementary site. I constructed 50 wire cages in order to enclose 50 seedlings and the other 50 seedlings were left as a control. The plots were revisited in May, July, and August of 2012 with additional height measurements recorded and any new browse occurrences noted. At time of caging, control seedlings (M = 15.93, SD = 5.53) did not differ significantly from caged seedlings (M = 15.45, SD = 5.39) by t-test ($t = 0.44$, $df = 97$, $P = 0.658$).

Data analysis. Minitab 16 was used in statistical analyses. Tests were significant if $P \leq 0.05$ and highly significant if $P \leq 0.01$. A binary logistic regression was used to test the relationship between browse likelihood and the effect of age, distance, and bud-capping.

Analyses were conducted on relative height growth (RHG) of seedlings for the following periods: First growing season (May through September 2011) (RHG_{t1}), second growing season (May through September 2012) (RHG_{t2}), and total growth (May 2011 through September 2012) (RHG_{tT}). Since the growth of a tree is related to its initial size (Puettmann & Reich, 1995), RHG was determined to be the appropriate measure to use instead of absolute growth. The following formulas were used to calculate RHG:

$$RHG_{t1} = (HT_{Sep11} - HT_{May11})/HT_{May11}$$

$$RHG_{t2} = (HT_{Sep12} - HT_{May12})/HT_{May12}$$

$$RHG_t = (HT_{Sep12} - HT_{May11})/HT_{May11}$$

where HT_{Sep11} is seedling height in September 2011, HT_{May11} is height May 2011, HT_{Sep12} is height September 2012, and HT_{May12} is height May 2012.

General linear models were used to test for significant effects on RHG associated with the seedling age, distance from road, bud-capping, pine bark adelgid presence, browsing, and their interactions.

Chapter III: Results

Browse Data

Table 3.1

Binary Logistic Regression on Relationship between Browse Likelihood and the Independent Variables Age, Distance from Road, and Bud-capping

Predictor	Coefficient	SE Coefficient	Z	P	Odds Ratio	95% CI	
						Lower Upper	
Constant	-3.96239	0.367717	-10.78				
Age	1.24203	0.18655	6.66	≤ 0.001	3.46	2.4	4.99
Dist	0.282455	0.177671	1.59	0.112	1.33	0.94	1.88
BC	1.18023	0.185479	6.36	≤ 0.001	3.26	2.26	4.68

Log-Likelihood = -390.323

Test that all slopes are zero: $G = 91.750$, $DF = 3$, $P\text{-Value} \leq 0.001$

Total Browse Occurrences (188 in total)

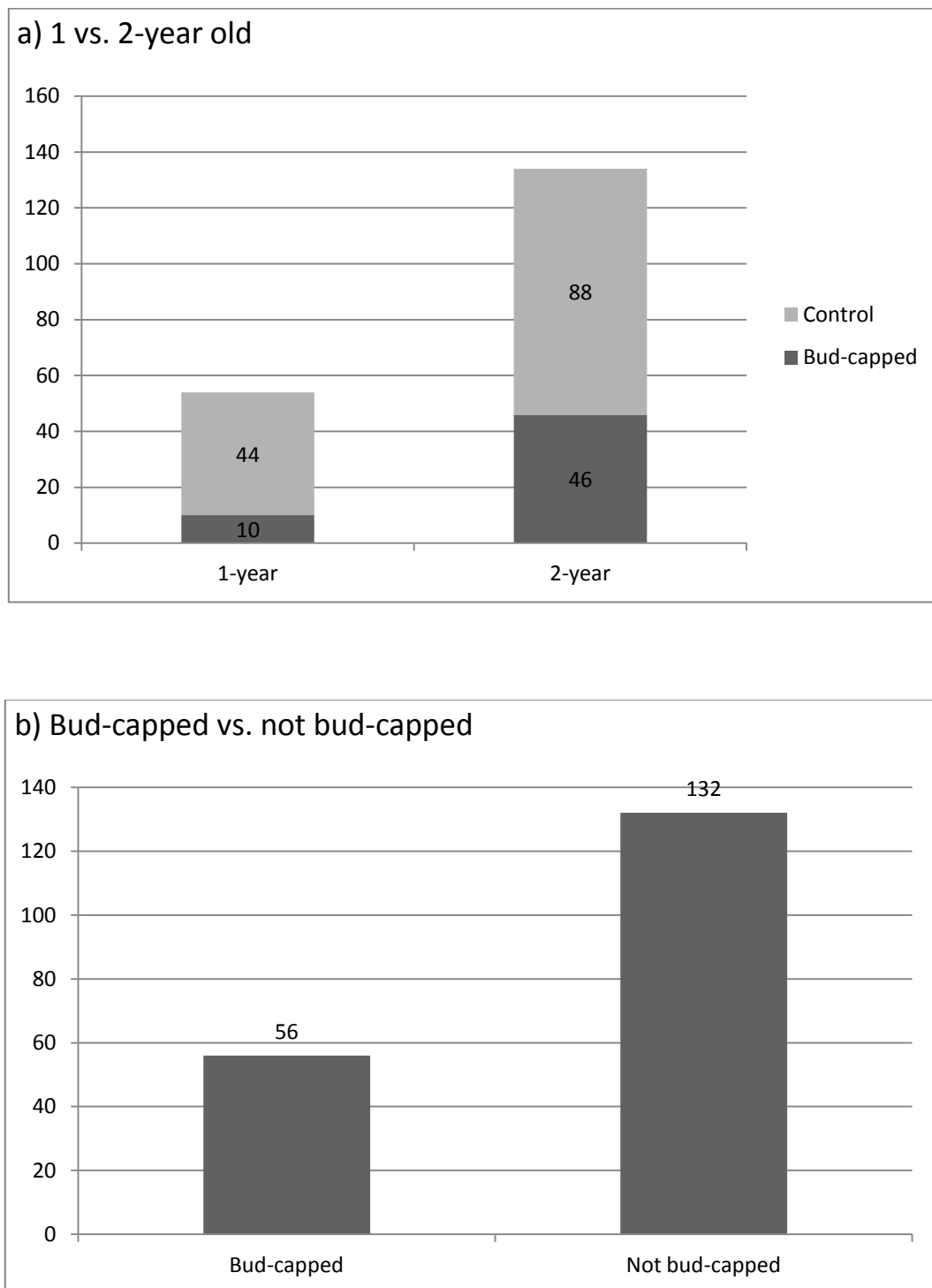


Figure 3.1. Total number of browse occurrences experienced by age and bud-capping.



Figure 3.2. Two-year old seedling with: a) Terminal growth in summer 2011; b) terminal leader damaged by bud-cap in winter 2011; c) bud-capped in fall 2012; d) browsed in winter 2012.

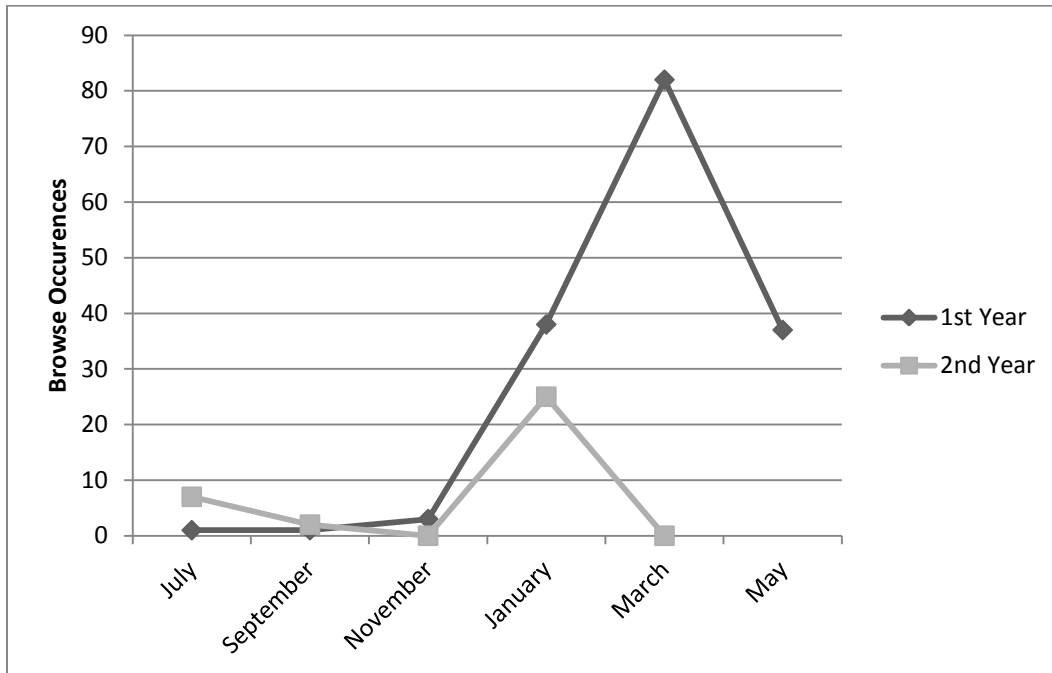


Figure 3.3. Browse occurrence by 2 month intervals for the 2 years of study.

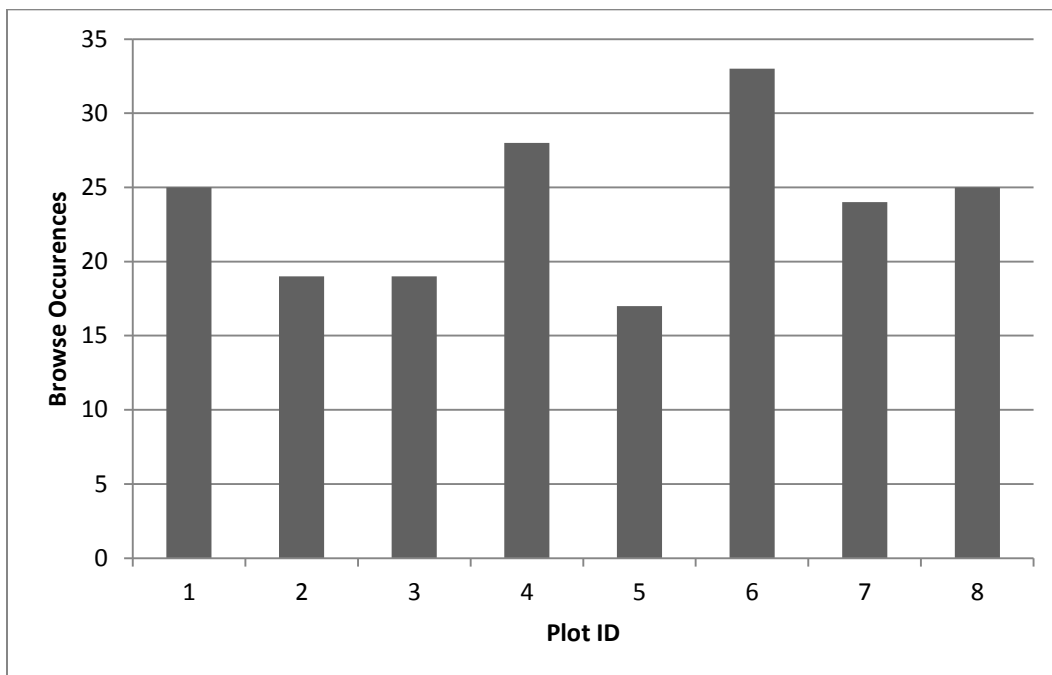


Figure 3.4. Browse history by individual plots through March 2013.

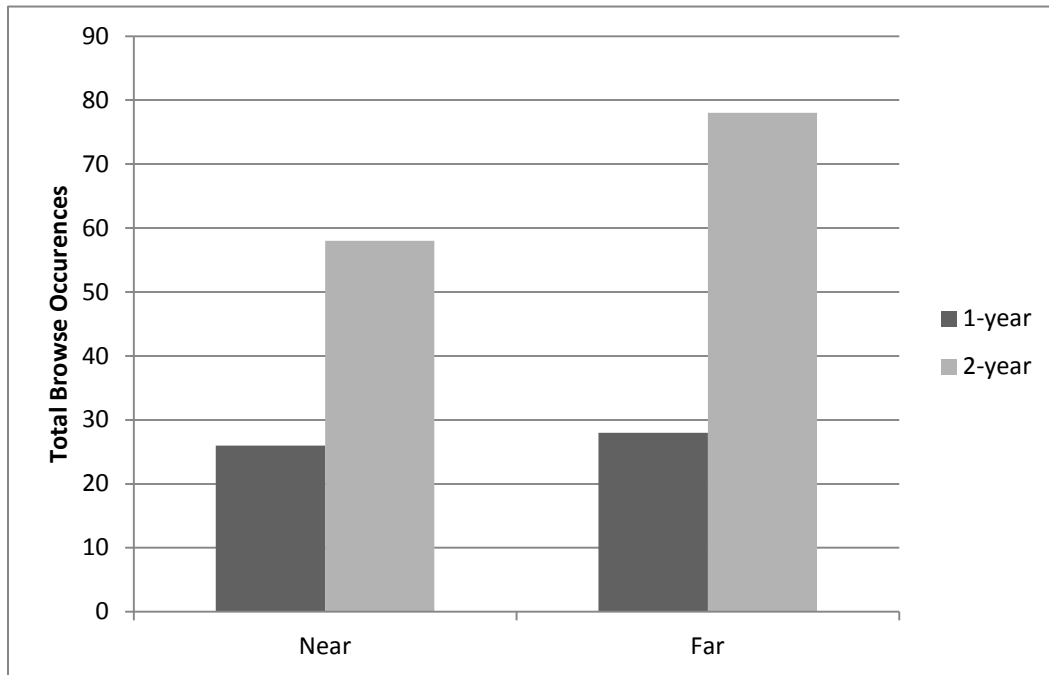


Figure 3.5. Total number of browse occurrences based on seedling age and distance from road.

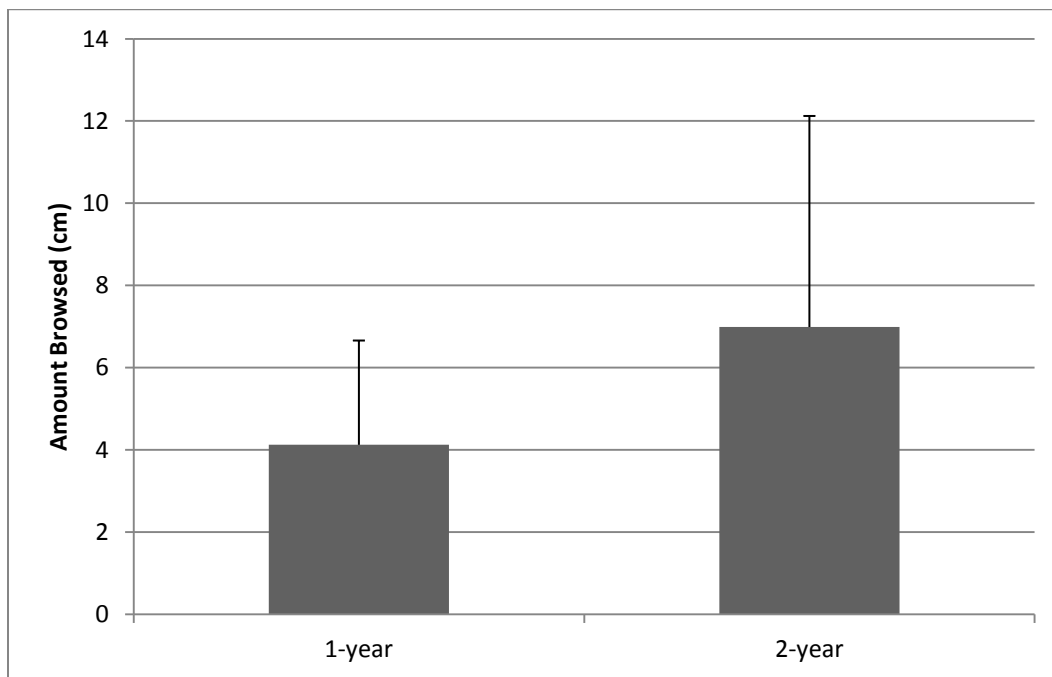


Figure 3.6. Total amount browsed on 1- and 2-year-old seedlings, error bars represent +/- 1 SD.

Table 3.2

Comparison of Seedlings Browsed or Not Browsed based on Height of Seedling

		Seedling Height (cm)					
		10-15	16-20	21-25	26-30	31-35	36+
Browsed	Yes	37	30	31	29	22	13
	No	295	113	80	71	37	19
	Total	332	143	111	100	59	32
Percent of Total		11.14	20.98	27.93	29	37.29	40.63

Pine Bark Adelgid

In July 2011 white, wooly masses were noted on the stems of multiple seedlings and by the following July they were present on nearly 200 seedlings. Pine bark adelgids (*Pineus strobi*) were identified to be the source of the white masses on the seedlings (Figure 3.7). By September 2012 a total of 58 seedlings had dead terminal leaders, 55 of which had pine bark adelgids present (Figure 3.8).



Figure 3.7. Two-year-old seedling infected with pine bark adelgids.



Figure 3.8. Terminal leader mortality with pine bark adelgids present.

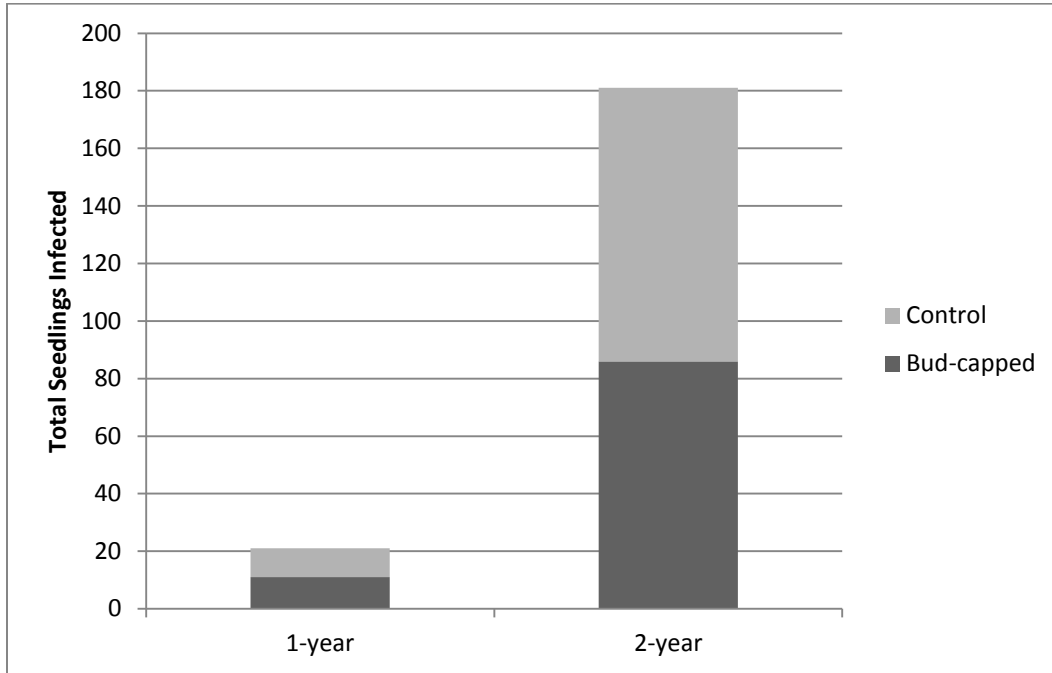


Figure 3.9. Pine bark adelgid presence by age and whether seedlings were bud-capped or not.

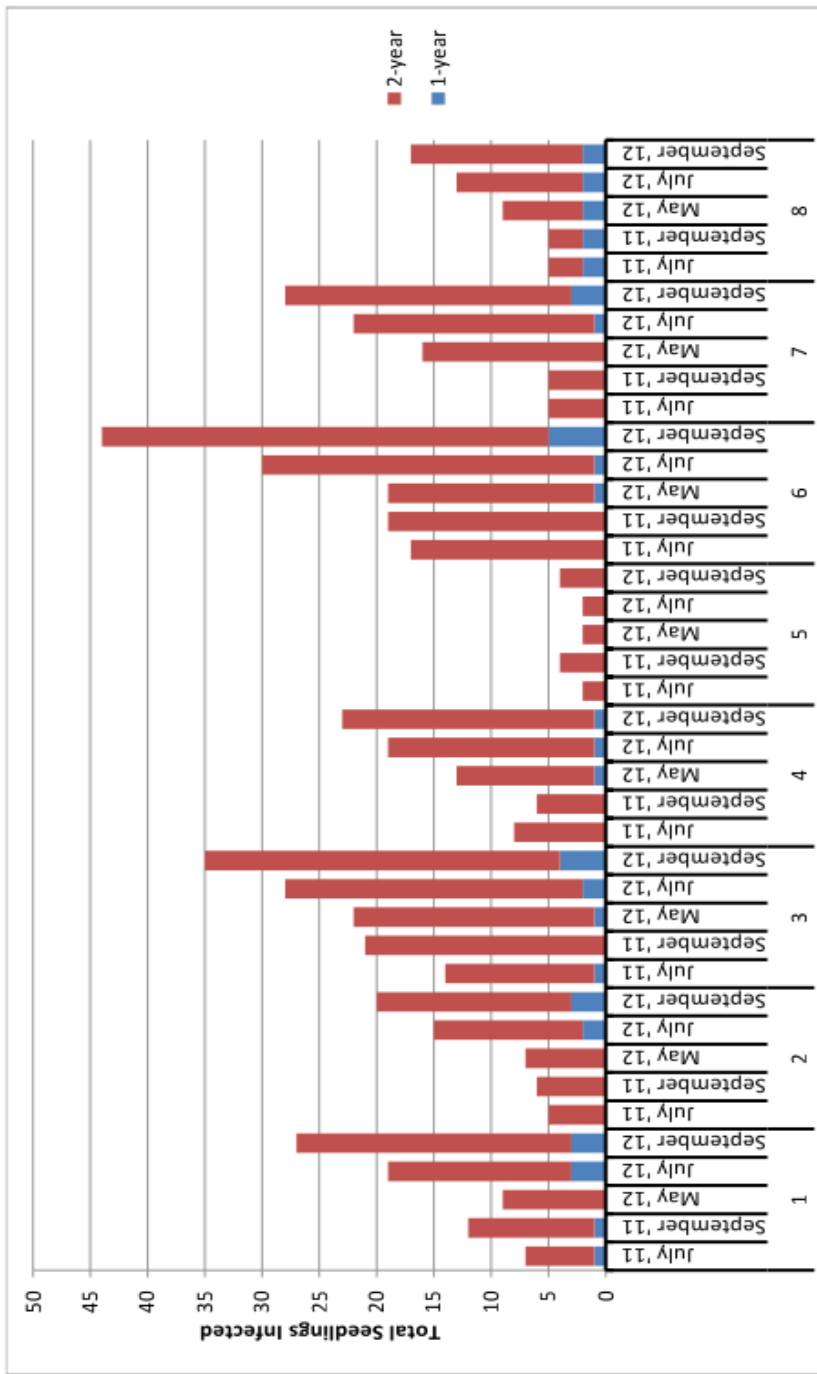


Figure 3.10. Total number of seedling infected with pine bark adelgids by plot, age, and month.

Growth Rates

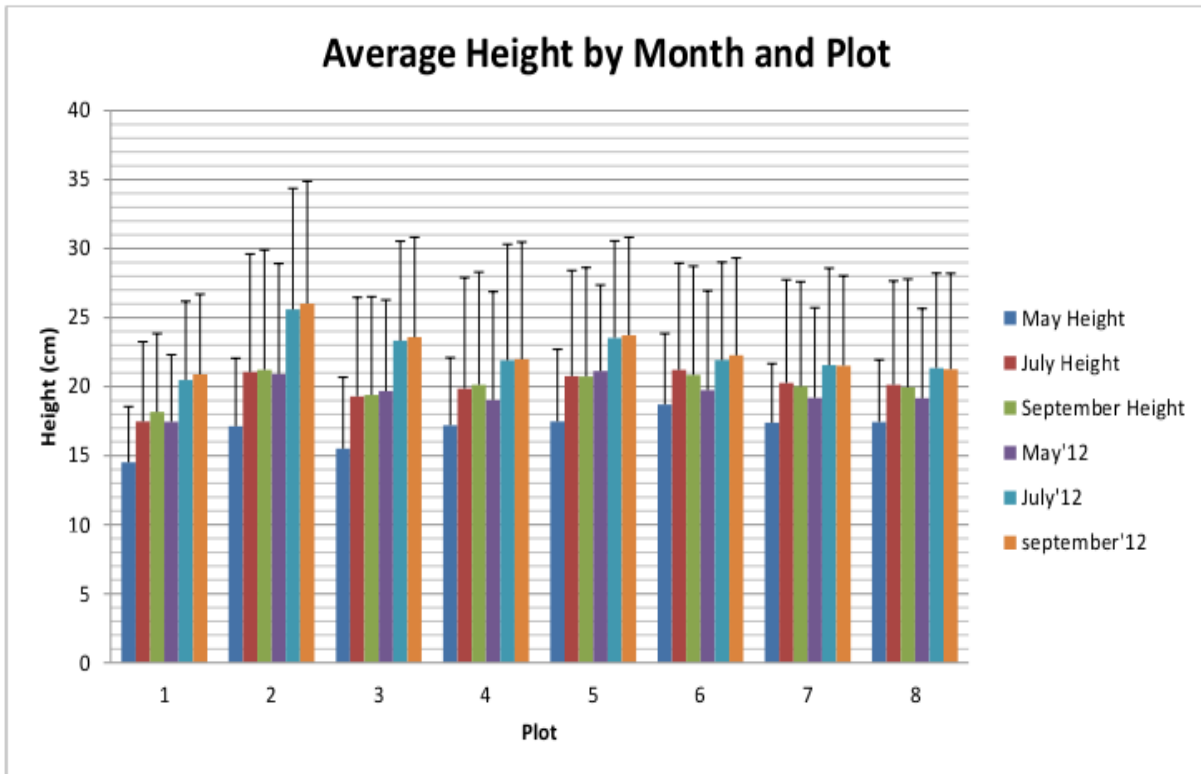


Figure 3.11. Average height of seedlings by plot through September 2012. Error bars represent ± 1 SD.

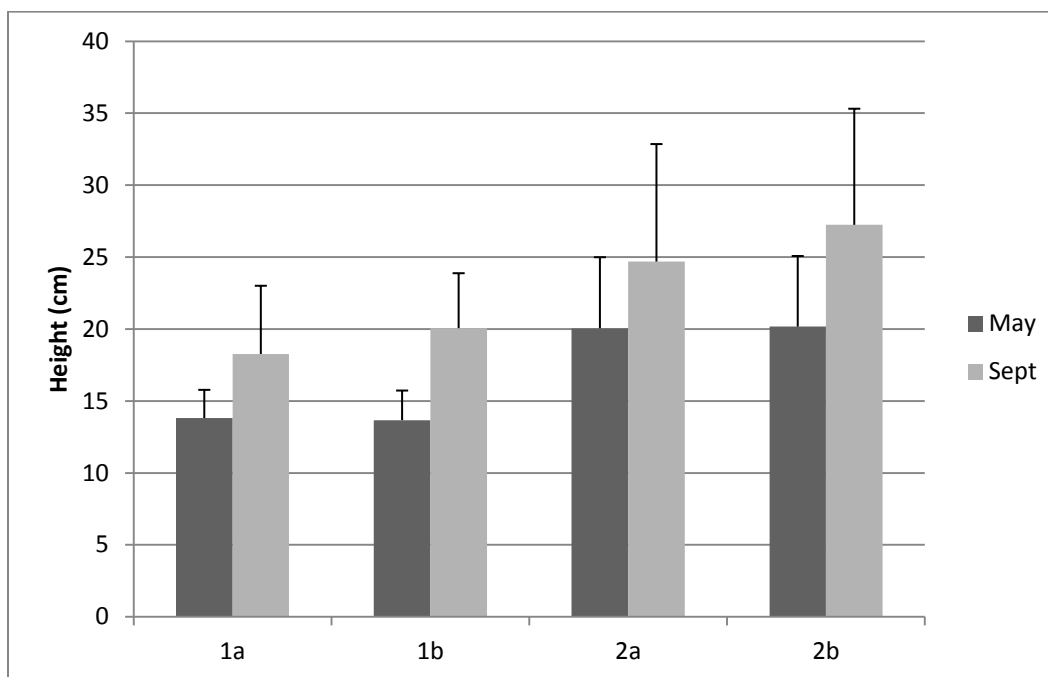


Figure 3.12. Comparison of average height of seedlings in May 2011 and September 2012. Error bars represent ± 1 SD.

Table 3.3

General Linear Model for RHGt1 Due to Effects of Age, Bud-capping, Distance, and Their Interactions

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	12.45	4.31	4.31	136.08	≤ 0.01
Bud-capped	1	0.007	0.00037	0.00037	0.01	0.914
Distance	1	0.78	0.32	0.32	10.09	≤ 0.01
Bud-capped x Distance	1	0.17	0.14	0.14	0.59	0.023
Age x Bud-capped	1	.017	.017	.017	.54	.461
Age x Bud-capped x Distance	1	.32	.32	.32	10.04	≤ 0.01
Error	769	24.61	24.61	0.032		
Total	776					

S = 0.178 R-sq = 37.28% R-sq (adj) = 36.05%

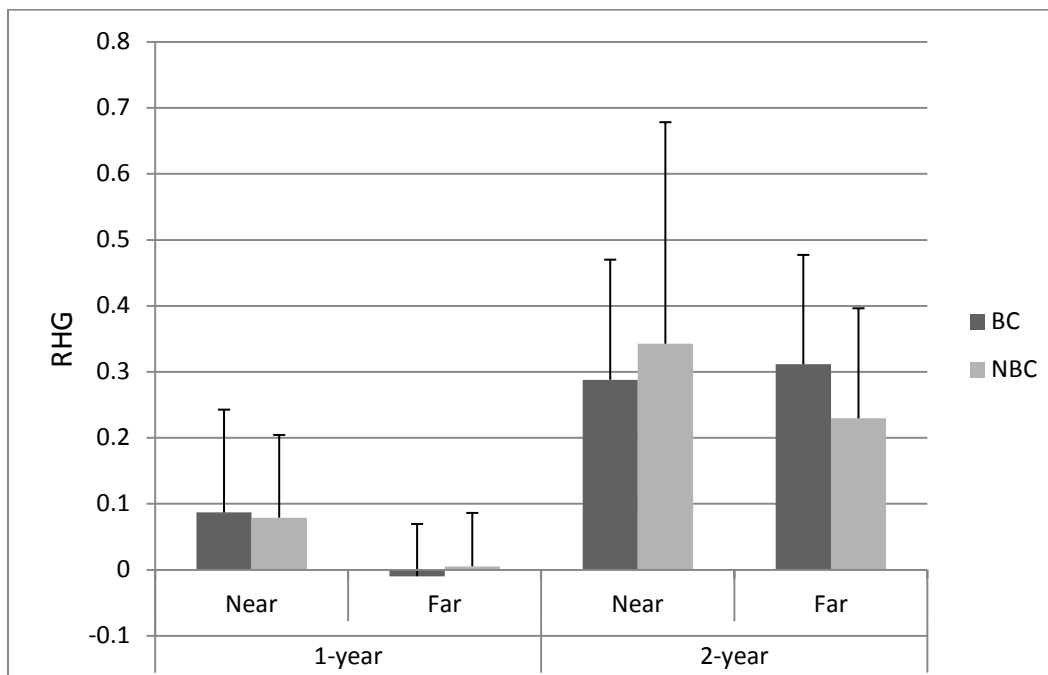


Figure 3.13. Comparison of RHG through September 2011 among age cohorts and treatments. Error bars represent +1 SD.

Table 3.4

General Linear Model for RHG₂ Due to Bud-capping, Age, Adelgid Presence, and Their Significant Interactions

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	4.73	1.48	1.48	66.92	≤0.01
Bud-capped	1	0.21	0.03	0.03	1.56	0.212
Adelgid Presence	1	1.2	0.3	0.3	13.75	≤0.01
Age x Adelgid	1	0.13	0.14	0.14	6.53	0.011
Bud-capped x Adelgid	1	0.18	0.18	0.18	8.04	≤0.01
Error	714	15.75	15.75	0.0221		
Total	719	22.2				

S = 0.149 R-sq = 29.08% R-sq (adj) = 28.58%

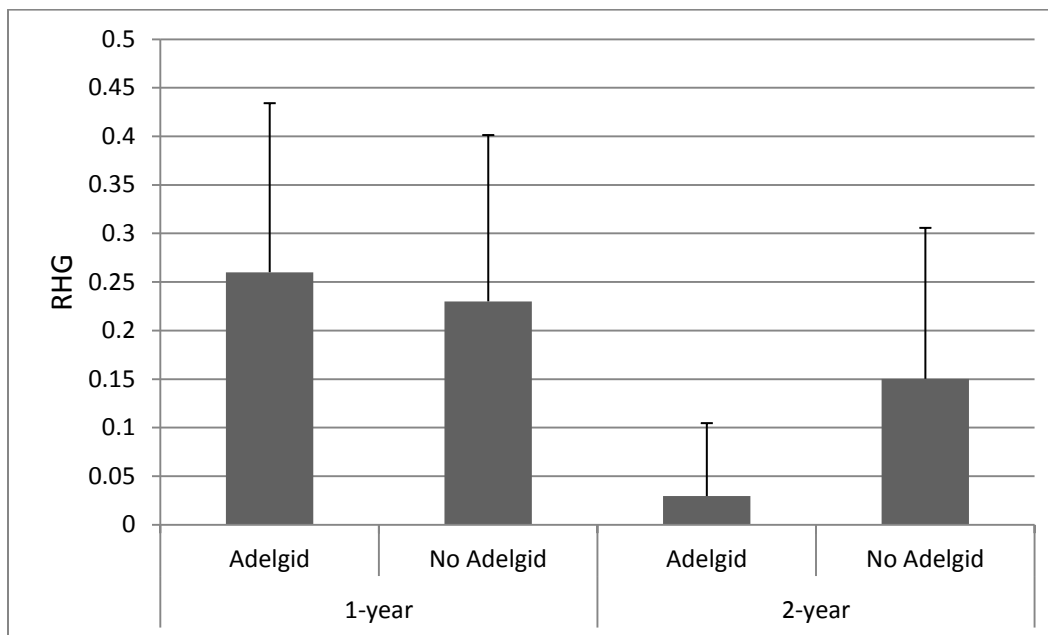


Figure 3.14. Comparison of RHG from May through September 2012 among age and adelgid presence or absence.

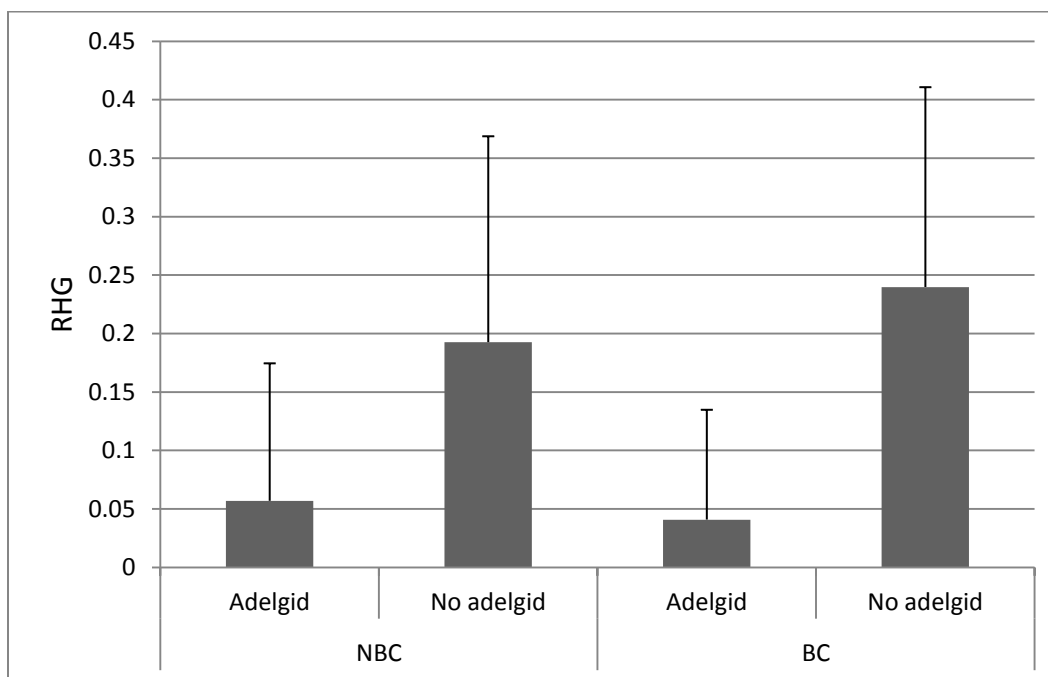


Figure 3.15. Comparison of RHG from May through September 2012 among bud-capping and adelgid presence or absence.

Table 3.5

General Linear Model on Factors Affecting Total Growth through September 2012

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	2.01	0.34	0.34	2.47	0.117
Bud-capped	1	3.2	0.89	0.89	6.54	0.011
Distance	1	2.2	2.1	2.1	15.38	≤0.01
Adelgid Presence	1	2.33	2.38	2.38	17.45	≤0.01
Bud-capped x Adelgid	1	1.99	1.99	1.99	14.59	≤0.01
Error	713	97.18	97.18	0.1363		
Total	718	108.92				

S= 0.369 R-sq= 10.78% R-sq (adj)= 10.15%

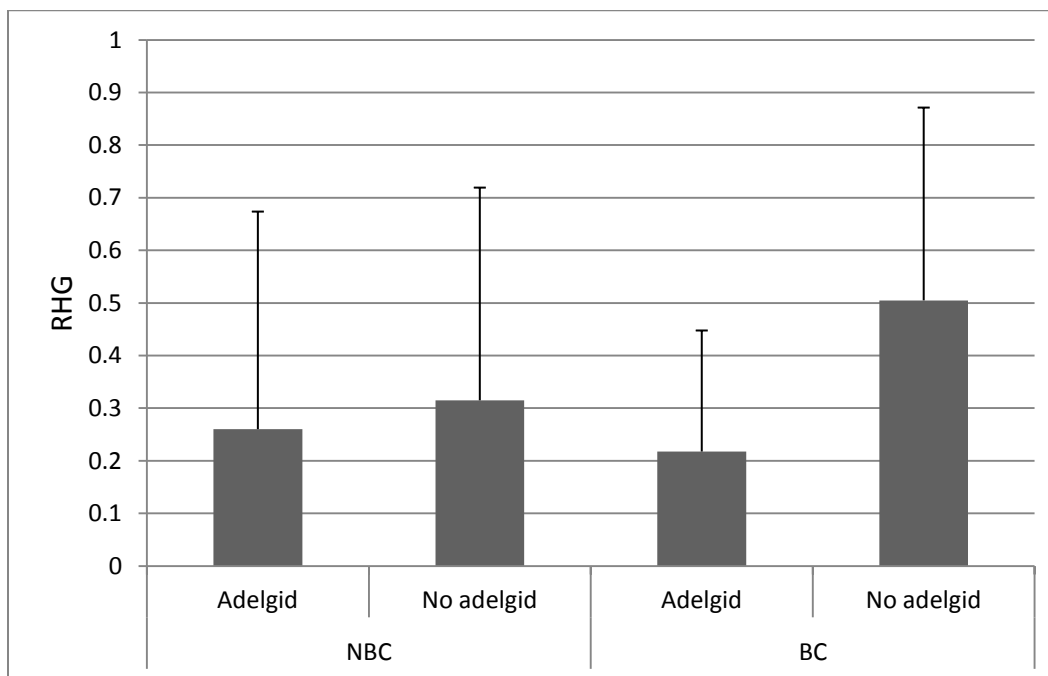


Figure 3.16. Comparison of RHG through September 2012 among bud-capping and adelgid presence or absence.

Table 3.6

Basal Area and Species Composition by Plot

Overstory Species Composition (%)												
Plot	Trees/ha	DBH range	Mean DBH	Basal Area/Plot	Basal Area/ha	RHG _t	Maple	Oak	Ironwood	Aspen	Birch	Ash
1	1616	3.5-65.0	15.61	13.14	52.57	.50	19.8	58.4	21.8			
2	1040	3.5-34.5	11.51	4.02	16.08	.51	4.6			15.4		80
3	1472	3.5-46.0	19.17	15.41	61.63	.57	34.8	25	18.5	8.7	13	
4	944	4-51.0	21.69	12	47.98	.28	37.3	27.1		6.8	28.8	
5	1392	3.5-47.0	18.28	12.93	51.72	.37	47.1	25.3	9.2	13.8		4.6
6	1520	3-53.0	12.05	8.28	33.12	.22	45.2	20	29.5	2.1	3.2	
7	1696	3.5-52.0	18.78	17.02	68.06	.24	48.1	36.8	5.7	2.8		6.6
8	1840	3.5-48.5	15	12.18	48.71	.22	40	18.3	37.4	1.7	2.6	

Table 3.7

General Linear Model for Browse and Adelgid Influence on Growth from May through September 2012

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Browse	1	2.59	1.11	1.11	50.71	≤0.01
Adelgid						
Presence	1	3.26	1.36	1.36	62.3	≤0.01
Browse x						
Adelgid	1	0.68	0.68	0.68	31.19	≤0.01
Error	716	15.67	15.67	0.0219		
Total	719	22.2				

S= 0.148 R-sq= 29.42% R-sq (adj)= 29.12%

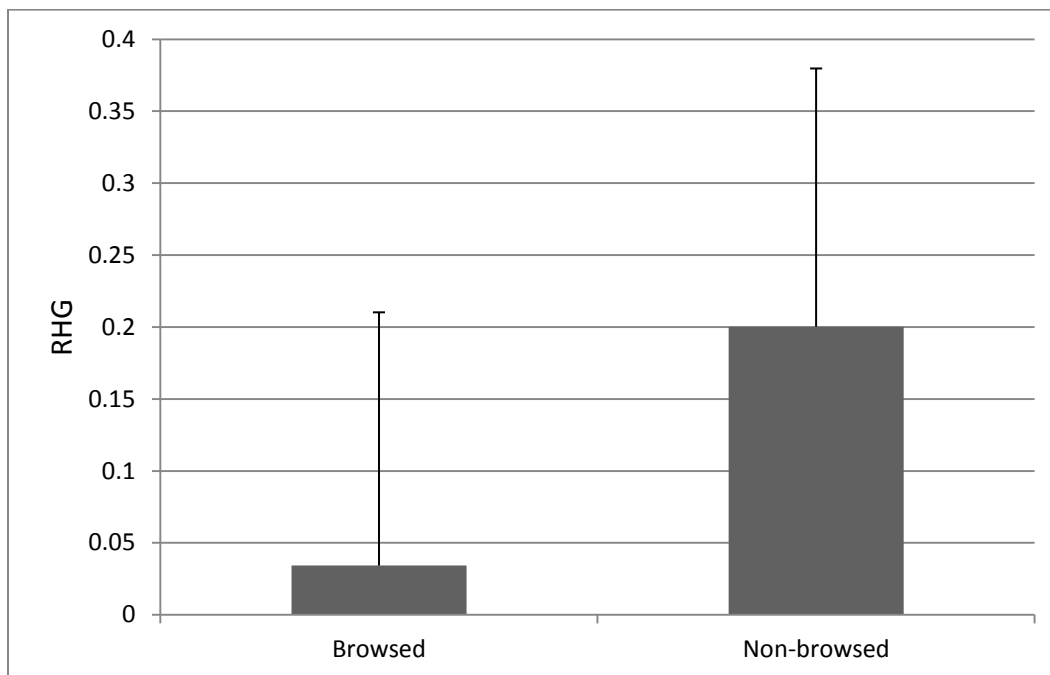


Figure 3.17. RHG_{t2} through September 2012 in seedlings that had or had not been browsed through May 2012.

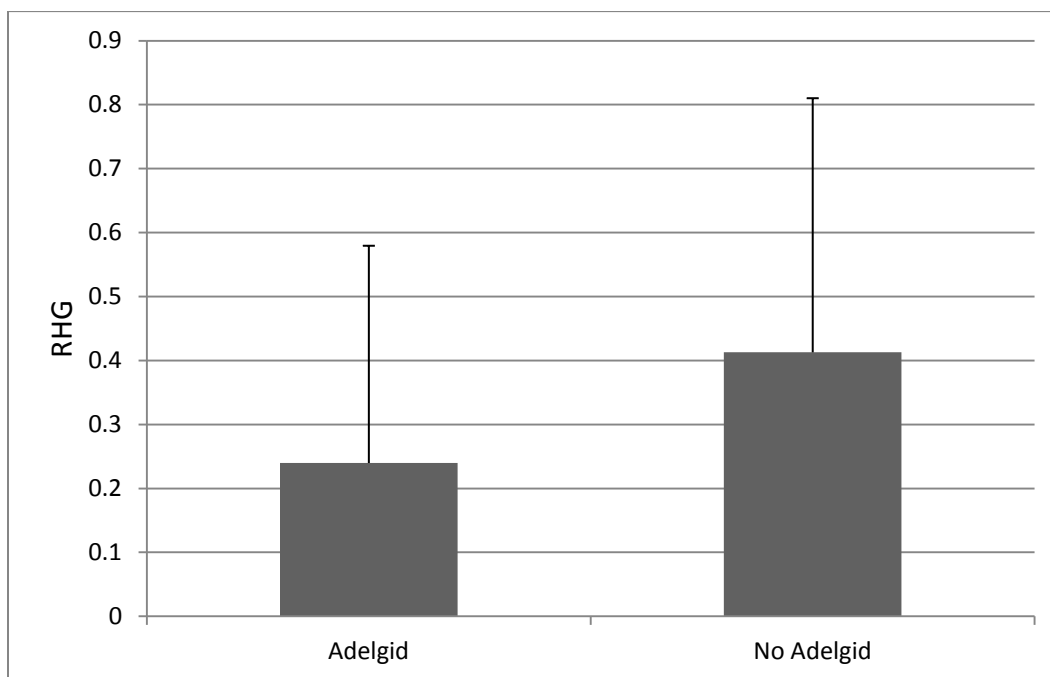


Figure 3.18. RHG_{t2} through September 2012 in seedlings infected and not infected with adelgids.

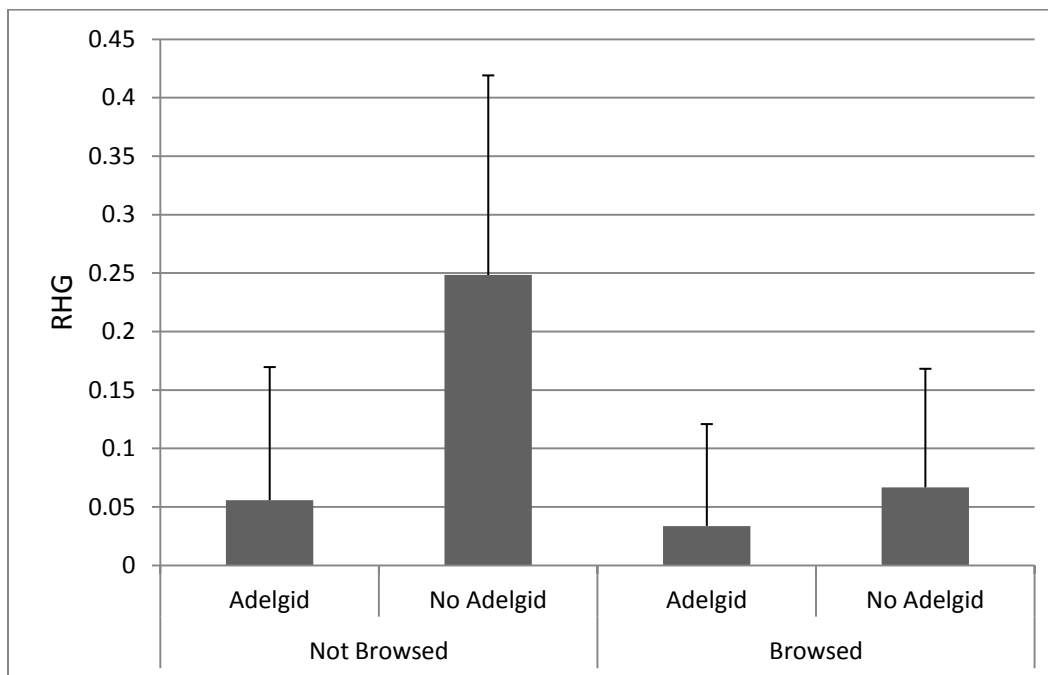


Figure 3.19. RHG₂ 2012 based on: Browsed x adelgid presence; browsed x adelgid absence; not browsed x adelgid presence; and not browsed x adelgid absence.

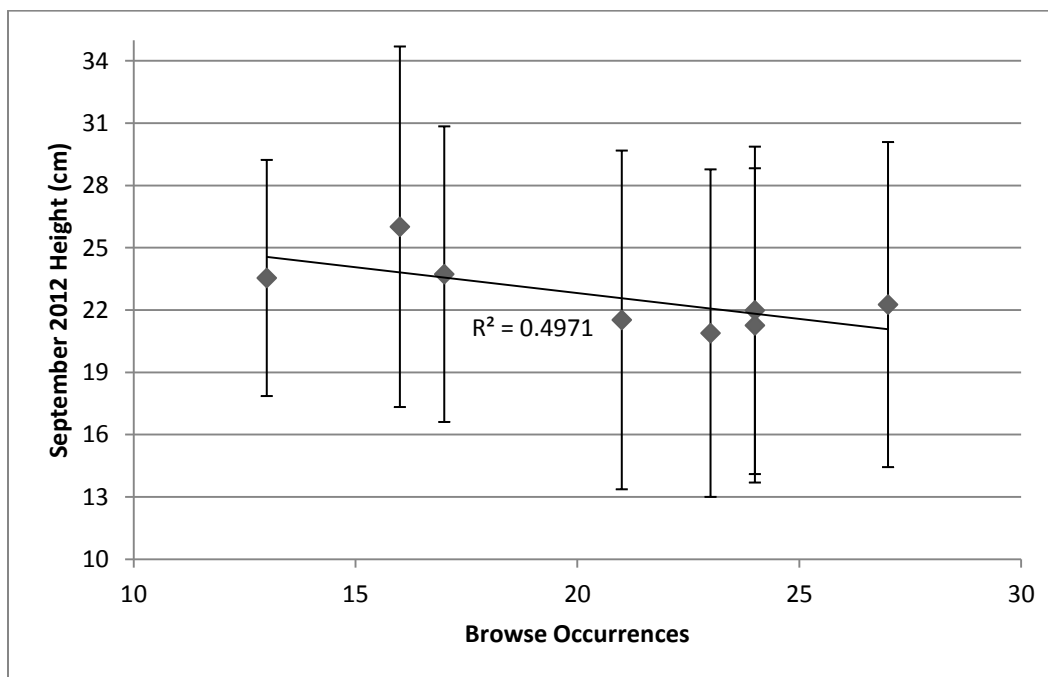


Figure 3.20. Relationship between total browse occurrences and September 2012 height.

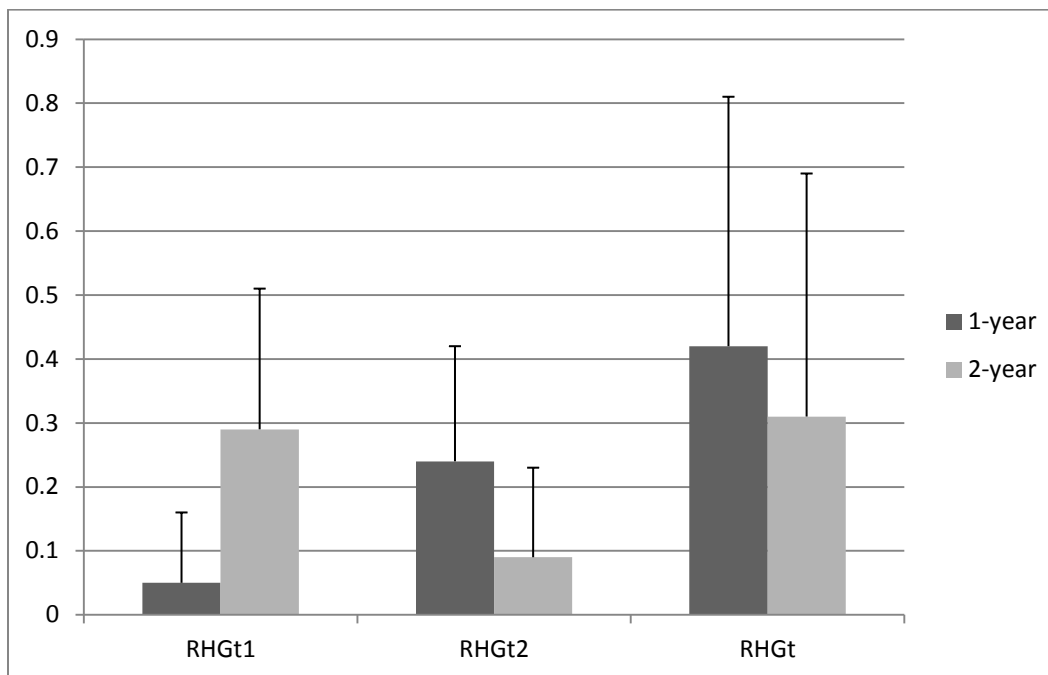


Figure 3.21. RHG values for first and second season growth and total growth.

In October 2012 a total of 38 control seedlings and 40 caged seedlings remained of the initial 100 flagged/caged the prior October. Seedlings that had been caged in the location south of the park office experienced significantly greater RHG rates ($M = 0.2$, $SD = 0.215$) than those left as a control ($M = 0.12$, $SD = 0.174$) by t-test ($t = -1.82$, $df = 74$, $p\text{-value} = 0.036$).

Mortality

A total of 90 seedlings, 63 one-year and 27 two-year-old, experienced mortality over the study period. A total of 8.5% of browsed seedlings succumbed to mortality, this accounted for 18% of total mortality. The average height of browsed seedlings dying was 18.23 cm, with a range of 10.5-35.0 cm. Mortality in browsed seedlings was equally represented by 1- and 2-year-olds. The months September through November experienced 48% of total seedling mortalities, with the apparent cause of mortality being stress associated with drought.

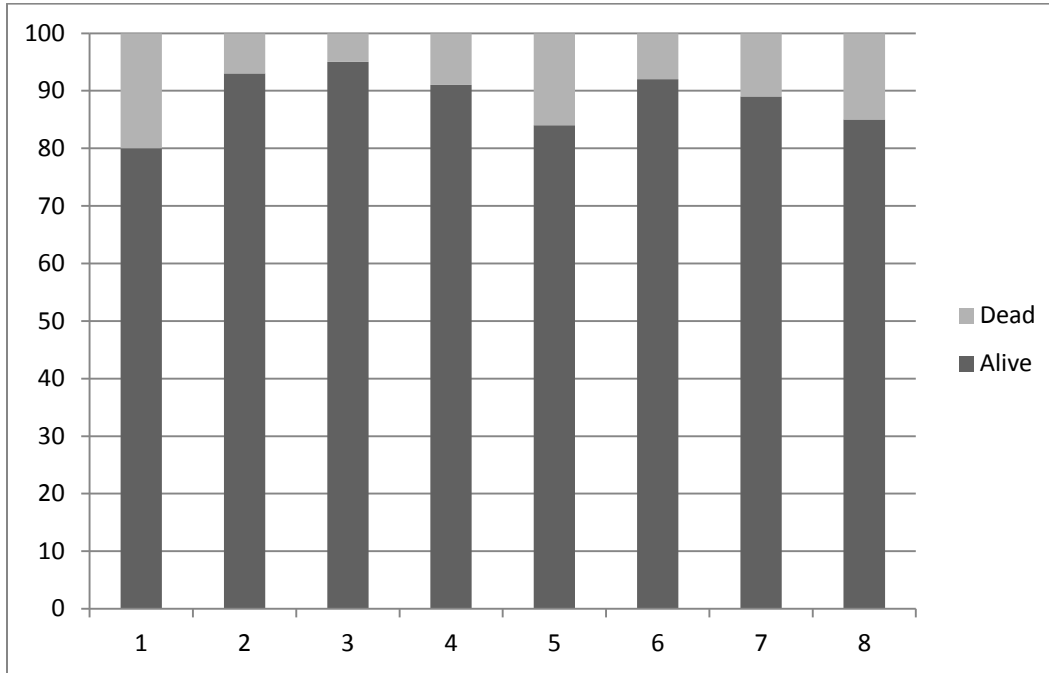


Figure 3.22. Mortality by plot.

Table 3.8

Sources of Mortality in Seedlings and Their Associated Types, Date of Mortality, and Plot

Plot	ID	Type	Date of Mortality	Source	Plot	ID	Type	Date of Mortality	Source
1	16	1b	11-Sep	Drought Stress '11	5	34	2b	12-Jul	Post-winter 2012
1	17	2b	11-Nov	Drought Stress '11	5	35	1a	12-May	Unknown
1	21	2b	11-Sep	Drought Stress '11	5	38	2b	11-Nov	Drought Stress '11
1	26	1b	12-Nov	Drought Stress '11	5	41	2b	11-Nov	Drought Stress '11
1	34	1b	12-May	Post-winter 2012	5	44	1a	12-Nov	Drought Stress '11
1	37	1a	11-Sep	Drought Stress '11	5	54	1b	12-May	Post-winter 2012w
1	38	2a	12-Nov	Drought Stress '11	5	60	1a	11-Sep	Drought Stress '11
1	45	2b	12-May	Post-winter 2012w	5	64	2a	12-Jul	Drought Stress '11
1	49	2b	12-Jan	Drought/Adelgid	5	91	1b	11-Sep	Drought Stress '11
1	57	1b	11-Sep	Browsed	5	94	1b	12-May	Browsed
1	60	2a	12-Mar	Drought Stress	6	14	1b	12-Nov	Trampled
1	64	2b	12-Sep	Trampled	6	33	2a	12-Mar	Browsed
1	68	1b	12-May	Browsed	6	47	2a	12-May	Browsed
1	76	2a	11-Jul	Post-planting	6	50	1a	12-Sep	Browsed
1	79	1a	11-Jul	Post-planting	6	63	1b	12-Nov	Drought Stress '11
1	84	1a	11-Sep	Browsed	6	76	1b	12-Nov	Drought Stress '11
1	88	1a	12-May	Unknown	6	92	2b	12-Jul	Post-winter 2012w
1	91	2a	12-Sep	Browsed	7	5	1a	12-Sep	Drought Stress '11
1	92	1a	12-Nov	Browsed	7	14	1b	11-Nov	Drought/Adelgid
2	48	1a	12-Nov	Browsed	7	23	1a	12-Jul	Unknown
2	59	1b	11-Sep	Drought Stress '11	7	53	2a	12-May	Browsed
2	68	2a	11-Sep	Drought Stress '11	7	66	1b	12-Jul	Post-winter 2012
2	71	1a	11-Sep	Drought Stress '11	7	67	1b	12-Nov	Drought Stress '11
2	83	1a	11-Sep	Drought Stress '11	7	77	2b	12-Jul	Browsed
2	98	1b	12-May	Post-winter 2012	7	78	1a	12-May	Unknown
3	13	2a	12-May	Unknown	7	84	1b	12-Jul	Post-winter 2012
3	21	1a	12-Sep	Drought Stress '12	7	89	1b	12-Jul	Post-winter 2012
3	39	1b	11-Nov	Drought Stress '11	7	90	2b	12-May	Browsed
3	42	1b	12-May	Browsed	8	2	1b	12-Jul	Post-winter 2012
3	50	1b	12-Sep	Drought/Adelgid	8	4	1b	11-Sep	Drought Stress '11
4	8	2b	12-May	Post-winter 2012	8	7	1a	11-Sep	Drought Stress '11
4	45	1a	12-Jan	Drought Stress '11	8	17	1a	11-Nov	Tree Fell
4	46	1b	12-Jul	Post-winter 2012	8	24	1a	11-Jul	Post-planting
4	51	2a	13-Jan	Top Dead	8	28	2a	12-Sep	Drought Stress '11
4	65	1b	12-Jul	Post-winter 2012w	8	30	1a	11-Sep	Drought/Adelgid
4	66	1a	12-Nov	Browsed	8	31	1b	11-Sep	Drought Stress '11
4	68	1b	11-Jul	Post-planting	8	38	2a	11-Sep	Drought Stress '11
4	69	2b	12-Jul	Post-winter 2012	8	47	2b	12-May	Post-winter 2012
4	96	1b	12-Jul	Post-winter 2012	8	64	1b	12-Sep	Drought Stress '11
5	3	1a	11-Sep	Drought/Adelgid	8	74	1b	12-May	Post-winter 2012
5	4	2b	12-May	Post-winter 2012	8	80	1b	11-Sep	Drought Stress '11
5	15	1b	12-May	Post-winter 2012	8	94	1a	12-Mar	Drought Stress '11
5	22	1b	12-Jul	Post-winter 2012	8	96	1a	12-Mar	Drought Stress '11
5	27	2a	11-Jul	Post-planting	8	97	1a	11-Sep	Drought Stress '11
5	28	1b	12-Jul	Browsed	8	100	1a	12-May	Drought/Adelgid

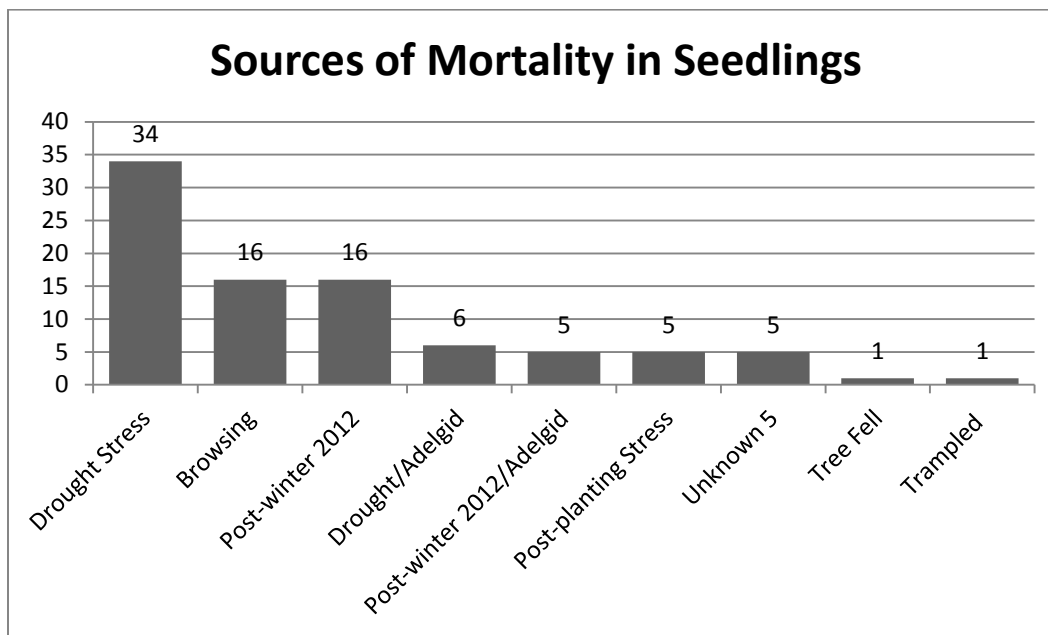


Figure 3.23. Sources of mortality in white pine seedlings at Mille Lacs Kathio State Park throughout study period (May 2011- March 2013).

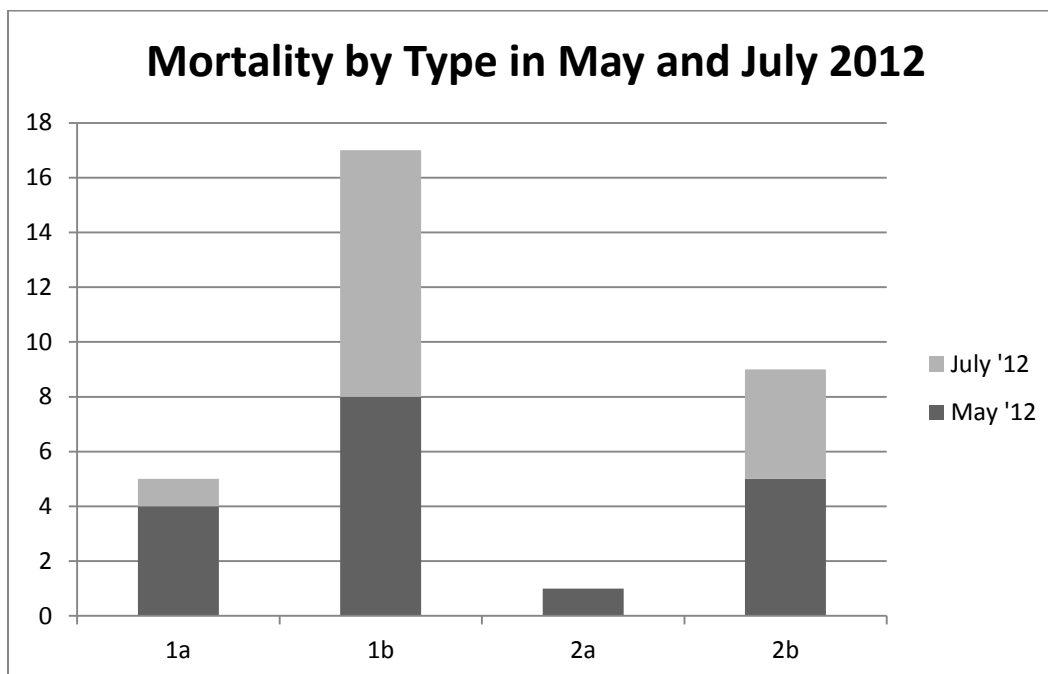


Figure 3.24. Mortality in seedlings by type in May and July of 2012.

Chapter IV: Discussion

My results support the hypothesis that 2-year-old seedlings would experience significantly higher browsing rates than 1-year-old seedlings. Bud-capping, as hypothesized, was successful at deterring browsing, independent of seedling age. Seedlings planted in plots near the road experienced less browse pressure, although not statistically significantly so, than those planted in plots far from the road; this was opposite of what was hypothesized. Two-year-old seedlings experienced higher survival rates than 1-year-olds, which was also opposite of what was hypothesized. Pine bark adelgids became established on a significant number of the planted seedlings throughout the two growing seasons of the study. Finally, as hypothesized, seedlings that were caged and therefore released from herbivory experienced significantly greater growth rates in the summer of 2012.

Browsing. Substantial browsing of white pine seedlings by white-tailed deer and snowshoe hare was recorded in this study. There were a total of 188 browse occurrences with just three being attributed to snowshoe hares. Over a 5-year period in northern Minnesota 43% of white pine seedlings experienced terminal browsing and 84% experienced lateral browsing (Krueger & Puettmann, 2004). A separate study in Minnesota found that 38% of seedlings experienced browse damage within a single year, with 17% of this total exhibiting terminal leader damage (Saunders & Puettmann, 1995). Similar to these studies I found high rates of browsing with 26% of available seedlings browsed throughout the study; however, I found higher terminal leader damage with every seedling browsed exhibiting terminal damage. There were no documented cases of lateral browsing; this is presumably due to the terminal leader being the most exposed and nutritious portion of the young seedlings and the

fact that the majority lacked lateral shoots the first winter of my study. Additionally, Hay and Rennie (1989) stated that when deer browse conifers they primarily target the current annual twigs and needles of the terminal leader and avoid lateral shoots.

My hypothesis stated that 2-year-old seedlings would experience higher browse rates than 1-year-olds. Two-year-old seedlings in fact experienced significantly higher browsing rates and were three times more likely to be browsed than 1-year-olds (Figure 3.1). Greater browse rates in 2-year-olds may be due to the fact that 1-year-olds, on average, are shorter than 2-year-olds and therefore less visible to deer. Browse occurrences reduced the height of both 1- and 2-year-old seedlings by a similar proportion of their total heights (Figure 3.6). In general larger seedlings were more likely to be browsed, regardless of age (Table 3.2).

Snow has the potential to cover seedlings and therefore make them less susceptible to browsing; this was not a factor in the winter of 2011-2012 since there was not sufficient snowfall to cover either age-class of seedlings. In contrast, the region had a recorded 101.9 cm of snow during the winter of 2012-2013 (UMN, 2013); which was sufficient to cover the majority of both age-classes of seedlings during the time period (January to March) in which seedlings experienced the greatest browse rates the year before. When I surveyed the seedlings in March 2013 just two seedlings were exposed above the snowline and neither of them had been browsed.

Previous studies have found browsing on seedlings less than 3 years old to be slight but subsequently becoming more intense on older seedlings (Hay & Rennie, 1989). Contrary to these findings, I documented high browse rates on the seedlings which were all 3 years old or less at the termination of the study. With nearly half of the browsing incidences taking

place between January and March of 2012, the lack of snowfall which resulted in decreased protection may explain this pattern. The authors recording slight browsing on 3-year-olds may have had a greater amount of snowcover during their study, effectively covering the younger seedlings and leaving older, larger seedlings susceptible to increased browse rates. Also since there were not any seedlings greater than 3 years of age in my study it is not known to what extent browse rates in older seedlings would compare to younger seedlings at Kathio. Finally, Kathio had a high population of deer during the winter of 2011-2012 prior to the in-park hunt which took place in November 2012 which resulted in the harvest of 72 animals. The high population of deer likely contributed to overall high browse rates in the winter of 2011-2012.

Bud-capping, as hypothesized, was successful at deterring browsing; seedlings without bud-caps were over three times more likely to be browsed than those that had bud-caps present (Figure 3.1). Ward and Mervosh (2008) found bud-caps to be effective at protecting terminal leaders on white pine seedlings over a 4-year period, with 1% of bud-capped seedlings experiencing herbivory and 20% of non-bud-capped seedlings being browsed. Additionally, Ward and Mervosh (2008) found just 2 of 80 seedlings survived over a period of 7 years on a site where no browse protection was used and these two averaged just 35 cm in height due to repeated herbivory events.

Bud-capping has not been shown to limit growth but does have the potential to break terminal leaders under adverse conditions such as strong winds and heavy, wet snowfall (Duddles & Edge, 1999); terminal leaders were broken in my study but the total was less than five. In my study the majority of browsing took place during the winter months of 2011-2013; this corresponds to the time of year in northern temperate regions when other food sources

have become depleted and browsing on white pine increases (Rogers et al., 1981). It is during these months that it is most important to utilize control methods to prevent damage associated with herbivory from deer in areas where browsing is anticipated.

It was hypothesized that seedlings located in plots near the road would experience greater browse rates than those in plots far from road; however, distance planted from road did not have a significant effect on these rates. In fact, seedlings planted in plots far from the road experienced slightly higher browse rates but there were no clear patterns across plots. Seedlings in plots located near the road were expected to experience higher browsing rates due to the anecdotal observation that deer forage on the abundant amounts of herbaceous vegetation located along the road. However, deer feed along the road edges primarily during the growing season when herbaceous vegetation is abundant. Theoretical foraging models suggest that deer are diet specialists when food availability is high (Nudds, 1980) and with nutrient-rich forage sources present, browsing on less nutritious conifer species is minimal. It is not until winter, which results in the absence of the nutrient-rich herbaceous species, that deer switch to a more generalists diet and are then more likely to browse conifers (Augustine & Jordan, 1998). The deer at Kathio appear to spend significantly less time near the road during winter and therefore browsing was not as severe as expected in near-road plots.

Pine bark adelgid. Pine bark adelgids, although typically not fatal to healthy trees, can be detrimental to seedling stocks. They frequently settle at the base of needles but do not feed on the needles; rather they feed on the sap located within the phloem layer which is responsible for transporting nutrients (Doane, 1961). To date they have not been a significant source of mortality at Kathio State Park, but were present on 202 seedlings in October 2012.

The adelgids appeared to be associated with terminal leader mortality in 2-year-old seedlings during the growing season of 2012; 95% of seedlings with terminal leader mortality had adelgids present to some extent. White pine weevils have similar feeding patterns and, although typically not fatal to seedlings, frequently kill terminal leaders (Krueger & Puettmann, 2004). Terminal leader mortality in my study was also likely associated with drought stress. The total rainfall was 24.43 cm in the region from July through October 2012, which was 9.55 cm less than the historic average and during this period the region was classified as being in a moderate drought. It is presumed that the combination of adelgids feeding on the sap, hence removing nutrients, and the drought stressed these seedlings and ultimately resulted in the terminal mortality.

There did not appear to be a clear pattern of infestations across the plots within the study area but adelgids did infect 2-year-old seedlings at significantly higher rates, regardless of the presence/absence of bud-caps. This may be attributed to the different nursery sources for 1- and 2-year-old seedlings, but adelgids have been noted to occur naturally on the landscape at Kathio in past years (Janet Smith, personal communication, October 18, 2012). It is also possible that the differently aged seedlings have different nutritional qualities. Seedlings with higher ratios of amino acids to carbohydrates are considered to be of a higher quality food source (Mittler & Meikle, 1991); therefore it would be expected to see higher infestation rates in higher quality seedlings. Further research is needed to explain the pattern of infestation observed at Kathio.

Previous research has shown that white pines planted in locations where understory vegetation had been removed have significantly higher rates of pine bark adelgid infestations

than trees in control groups where vegetation had not been removed, 19.8% vs. 3.8% (Krueger & Puettmann, 2004). The authors suggested this pattern may be due to the fact that surrounding vegetation conceals the seedlings and therefore makes them less susceptible to infestation. Interestingly, plot five in my study had a total of four seedlings infected, and like the other plots, experiences minimal understory competition and has a closed deciduous canopy. Plot six had the highest number of seedlings infected; the reason for this is unclear due to the similarity this plot has with the other plots in regards to overstory species composition, understory competition and SBA.

Adelgid infections increased steadily between May and September 2012. This period correlates when eggs are hatching into crawlers, and since they are capable of having up to five generations each year (Doane, 1961) new infestations throughout the growing season are expected. Although the majority are wingless and will remain on the tree they hatch on, winged crawlers are able to disperse and become established on nearby trees. It appears that winged crawlers may be abundant only in certain years (Doane, 1961); therefore white pines in certain years may see a dramatic spike in new infestations.

Since new adelgid infestations appear to be minimal when seedlings are grown with understory competition (Krueger & Puettmann, 2004) future restoration at Kathio may want to consider this option as opposed to open site plantings.

Growth rates. Prior research has indicated that the majority of terminal growth occurs between late May and the beginning of July in Minnesota (Stearns, 1992). This was supported in this study with the majority of growth occurring from May through July, then decreasing considerably thereafter during each growing season.

Distance planted from road had a significant effect on growth during the first growing season. This appeared to have a greater effect on the 1-year-old seedlings; those located near road had greater RHG than those in plots far from road. Plot two had a negative RHG and plot four had minimal RHG compared to other plots for 1-year-old seedlings. These two likely brought the averages down for the four far plots and yielded the results. Reasons for the minimal or decrease in growth for these two plots are unclear; SBA did not have a significant influence on growth and would not have contributed to this pattern. There may be soil variations attributing to greater growth in plots near the road: 70% of the soil in the area is classified as being a sandy loam but local site variations may result in greater productivity in certain plots. To investigate this soil samples should be collected within each plot and analyzed.

Two-year old seedlings experienced greater RHG rates the first growing season; however, 1-year-olds experienced greater growth rates the second growing season. Overall, 1-year-old seedlings experienced slightly greater total growth over the two seasons. Two-year old seedlings had well established terminal buds the first season whereas the 1-year-olds did not; this likely explains the 2-year-olds experiencing greater growth rates the first season.

There are several likely reasons for the pattern of 2-year-olds experiencing minimal growth rates the second season; the first being that 2-year-old seedlings experienced significantly higher browse rates in the winter of 2011-2012 (Figure 3.3). Growth in post-browsed seedlings during the second growing season was minimal, likely due to the seedlings allocating resources to repair rather than grow. Tilghman (1989) kept white-tailed deer at fixed densities between zero and 31 per square kilometer for 5 years. At the end of the study,

seedlings grown where deer densities were the highest were 50% the height of those grown in plots absent of deer. This has implications for Kathio where seedlings are exposed to repeated browsing from deer.

Secondly, 2-year-olds had disproportionate adelgid presence and seedlings infected with adelgids, regardless of age, showed minimal growth during the second season. This resulting minimal growth in seedlings infected with adelgids is likely to be due to the fact that the adelgids feed on the phloem layer, reducing available nutrients the seedling has to allocate to growth. Interestingly, Krueger and Puettmann (2004) found no instances of dieback, reduced growth or vigor for the seedlings with adelgids present; this may be due to their seedlings being 3 years old at time of planting and overall had lower infestation rates with 15% of the seedlings infected. Finally, only 2-year-olds in the study experienced terminal leader mortality and these mortalities occurred during the second growing season. Those that had experienced terminal mortality exhibited minimal growth during the second season. For a comparison, during the second growing season 148 two-year-old seedlings had not been browsed nor had adelgids present and these had 0.1809 RHG; 300 one-year-old seedlings that had the same condition and a RHG value of 0.2667. In the growing season of 2011 two-year-old seedlings, which had not been browsed nor had adelgids present, experienced an RHG value of 0.2812.

Browsing on conifer seedlings has the potential to stunt growth which ultimately effects regeneration (Whitney, 1984). Previous research has shown that when the terminal shoot is browsed one or more adventitious buds form new shoots which then assume terminal positions (Hay & Rennie, 1989). This was the case for several 2-year-old seedlings, but many

lacked lateral shoots to allow for this pattern and therefore will likely remain stunted for several growing seasons. Research on compensatory growth in white pine seedlings following herbivory found that there is an increase in RHG at low intensities (Puettmann & Saunders, 2001). The seedlings in my study showed very minimal or no RHG following a browsing event, again this pattern is likely due to the fact that many seedlings lacked sufficient lateral shoots to compensate for browsing. To better understand these patterns research on herbivory on larger seedlings with lateral shoots should be conducted.

There was a significant interaction between age and adelgid presence on growth during the second season. The 1-year-old seedlings exhibited similar growth rates whether or not adelgids were present; however, 2-year-olds without adelgids present experienced significantly greater growth than those with adelgids present. This relationship is likely due to the small numbers of 1-year-olds infected compared to 2-year-olds; there simply were not enough 1-year-olds infected to see a clear pattern. Also, the 1-year-olds that were infected had low intensity infestations (i.e., small proportion of the stem exhibited the white, wooly mass).

The interaction between bud-capping and adelgid presence also had a significant influence on growth during the second season. Seedlings, regardless of presence/absence of bud-caps, when not infected with adelgids experienced greater growth than those with adelgids present. Krueger and Puettmann (2004) noted that although rarely causing mortality in seedlings in Minnesota, adelgids may slow growth rates. Interestingly, infected seedlings that had not been browsed had lower RHG rates than those browsed but not infected. So although bud-caps are effective at deterring browsing, if bud-capped seedlings become infected with adelgids they will experience minimal growth. There is not an association

between bud-caps providing protection for adelgids due to the fact that adelgids infestations in this study frequently occupied the entire length of the stem.

Seedlings that had been bud-capped experienced the greatest amount of growth throughout the study; this is presumably a direct result of the bud-caps' effectiveness at deterring browsing. Adelgids also had a significant effect on total growth; those not infected with adelgids had nearly two times greater total RHG than those infected. The fact that seedlings infected with adelgids experienced nearly no positive growth the second season led to this result. Finally, distance also had a significant effect on total growth. There was a relationship between total browse occurrences per plot and total height in September 2012. Since plots near road experienced fewer browse occurrences it would be expected that they have greater RHG rates.

Seedlings that were caged at the location south of the park office experienced greater RHG rates than those not caged presumably due to the fact that they no longer were subject to browsing. The seedlings that were not caged at this site continued to experience browse occurrences, which directly affected their RHG rates.

Mortality. Causes of death in the Great Lake states were previously identified as being primarily associated with disease (57%), weather (26%), animals (12%) (Spencer et al, 1992). White pine causes of death in my study were primarily due to weather (38%) and animals (18%). Disease was not identified as a cause of death in my study and insect mortality was minimal. There were no clear relationships with mortality across plots in my study. Plot one had the greatest number of seedlings experiencing mortality but like other plots, has similar characteristics. Wetzell and Burgess (2001) stated that nutrition of seedlings correlates

with health and vigor and this can ultimately influence survivability. There is likely variation in soil and nutrient availability across my study plots and this has the potential to influence the mortality rates observed in my study.

The single greatest factor associated with mortality over the study period was drought stress ($n = 34$), and an additional three deaths were associated with drought stress along with presence of adelgids. White pines are intolerant of extended periods of drought and high temperatures (Ahlgren, 1976); the second half of the growing season in 2012 was classified as being in a moderate drought. Relatively low precipitation occurred during the later portions of the two growing seasons; August through September of 2011 and 2012 saw 15.11 and 6.02 centimeters of rain, respectively. The historic average for this time period is 16.43 centimeters.

Katovich, O'Brien, Mielke, and Ostry (2004) found high mortality rates associated with white pine seedlings that had been browsed. Conversely, over the course of my study I found low mortality in seedlings post-browsing; it is yet unclear if additional seedlings that had been browsed will experience mortality in the future. As a comparison, 22 of the 100 seedlings in the study site south of the park office died during summer 2012 and all of these had experienced browsing in the past. Seedlings may not experience mortality immediately following a herbivory event due to their ability to allocate resources to repair damaged tissue and therefore higher mortality rates may be contributed to herbivory in following seasons at Kathio. This is especially the case if environmental conditions are unfavorable for survival (i.e., drought, high temperatures).

Seedlings experiencing mortality from browsing were equally represented by 1- and 2-year-olds. There was no consistent pattern between seedling height and likelihood of experiencing mortality (i.e., small seedlings were not more likely to experience mortality following a single herbivory experience than large seedlings).

There were a disproportionate number of 1-year-old seedlings which experienced mortality than 2-year-old seedlings. It was hypothesized that the 1-year-old seedlings would experience higher survival rates than 2-year-olds due to their roots becoming established earlier than bare-root 2-year-olds. Large (4-year-old) seedlings were found to have higher mortality rates than small (2-year-old) seedlings at Kathio during the summer of 2007 (N. Dryden, unpublished data). In my study approximately 33% of total deaths in each cohort died the first growing season (the season expected to see disproportionate 2-year-olds dying due to post-planting stress). There were no clear patterns thereafter in regards to time of year of mortality or source; each age class appeared to be equally represented by time and source of mortality just with 1-year-olds having higher rates.

Twenty-six seedlings experienced mortality between May and July of 2012. These seedlings were recorded as healthy the previous winter and upon further analysis 21 had been bud-capped the prior winter. Previous research has shown that paper bud-capping can lead to seedling mortality on dry, hot sites due to heat or water loss (DeYoe et al., 1985). The spring of 2012 saw an early onset of the growing season and the bud-caps may have contributed additional stress on the seedlings since they were not removed until early May. This has especially been shown to be true in instances where the terminal leader fails to grow beyond the bud-cap in the spring. Although bud-caps prove effective at deterring browsing, they may

result in increased mortality if not manually removed from the seedling in early spring. With bud-capped seedlings experiencing just 56 browse occurrences compared to 132 occurrences in those not bud-capped, their effectiveness in deterring browsing appears to outweigh the potential mortality associated with them.

Although not a significant contributor to seedling mortality to date, pine bark adelgids may further stress already infected seedlings and cause mortality in the future. The plots in my study do not experience much understory competition and previous research has shown infestations to occur at significantly higher levels in areas with minimal understory competition (Krueger & Puettmann, 2004). Since pine bark adelgids appear to be associated with terminal mortality, the seedlings are potentially losing a couple seasons of terminal growth and therefore will remain more susceptible to browsing from deer for a longer period of time. Future white pine plantings may want to consider locations where there is, to some degree, understory competition in an attempt to minimize impacts from pine bark adelgids.

Chapter V: Conclusions

Repeated deer browse injury has been shown to be one of the greatest limiting factors in white pine seedling establishment in Minnesota (Mielke et al., 1989). Deer have a direct effect on conifers by stunting the growth of seedlings through browsing, ultimately affecting successful establishment (Whitney, 1984). Damage caused by deer on seedlings is related to densities of deer and seedlings, seedling size, and abundance of other food (Reimoser, 2003); damage on white pines decrease once the tree reaches nine feet tall or has been planted for 11 years (Sauerman, 1992). Bud-capping in this study was successful in deterring browsing from white-tailed deer during the winters of 2011-2012 and 2012-2013. Since browsing pressure increased in seedlings greater than 15 cm it is important these larger seedlings be protected. The level of protection bud-caps provide outweigh the potential mortality associated with them due to additional stress they may create at the onset of the growing season. Distance seedlings were planted from road did not have a significant influence on browsing rates so this consideration should not be weighed as heavily as browse deterrents.

It is yet unknown the extent of mortality that will be associated with pine bark adelgids in the seedlings currently infected. The presence of adelgids, coupled with drought stress, may ultimately lead to high mortality rates in the future that the current study were unable to quantify. It is pivotal that future restorations consider the seedling source (i.e., nursery) in order to select seedlings that are less prone to be hosts of the insects.

One-year-old seedlings experienced a mortality rate of over two times than that of 2-year-olds throughout the duration of the study, with a large percentage of the mortalities occurring during the first growing season and in the spring of 2012. Again, it is yet unclear

the extent of mortality which may result in 2-year-olds from pine bark adelgids so there may be a benefit to planting seedlings, with a higher initial mortality rate, that are not as susceptible of a host to the insects. In the long-term the benefits of not suffering from terminal leader mortality, reduced vigor, and reduced growth rates associated with the adelgids may outweigh the initial mortalities.

White pine seedlings in this study were planted under a closed deciduous canopy, which is representative of the landscape at Kathio. Previous research has shown white pines grown under deciduous canopies to have moderate survival rates but experience significantly lower growth rates than those planted in locations without a canopy present (Abrams, 2001; Ward & Mervosh, 2008). Increases in height, diameter, and total biomass growth in white pine seedlings have been documented to occur when there has been overstory removal or understory vegetation control (Puettmann & Saunders, 2000; Wetzel & Burgess, 2001); this practice allows for more light to reach seedlings and potentially more access to nutrients and water due to less competition. Pitt et al. (2009) also suggest that early management of understory competition should be implemented for successful seedling establishment.

This previous research has significant implications for restoration at Kathio and in the future overstory release and planting in open areas may be considered. Increasing light availability to seedlings will increase annual growth rates and therefore potentially allow seedlings to escape detrimental effects from browsing earlier. However, reducing the overstory may result in greater understory competition and seedlings may succumb to this competition. Herbaceous competition can result in reduced survival and growth rates in seedlings by reducing the availability of moisture, light and nutrients (Stiell, 1985). The

competing vegetation can also reduce survival and growth of the seedlings by limiting photosynthetically active radiation (Brand & Janas, 1988). However, herbaceous competition has been shown to provide protection from browsing (Saunders & Puettmann, 1995), white pine blister rust (Krueger & Puettmann, 2004), pine bark adelgids (Krueger & Puettmann, 2004), and reduce terminal shoot damage from white pine weevil (Pitt et al., 2009). Krueger and Puettmann (2004) noted that removal of herbaceous vegetation failed to improve seedling growth within their study plots so therefore controlling understory competition may not be necessary

Restoring the conifer component, when it has been lost, is important in order to increase habitat diversity and restore pre-settlement conditions. Restoring this component in Kathio's forest will continue to be a challenge in the future due to disease, insects, climate, and deer densities. Understanding these threats and the impact they have at a landscape level is essential to having a successful restoration program. Previous research has shown white pine seedling growth and survival rates to increase through management of over- and understory vegetation, but seedlings grown in these conditions are also more susceptible to browsing, disease and insects (Krueger & Puettmann, 2004).

My research has helped understand the pre-settlement condition of the forest, what led to the system being degraded, the importance of the conifer component on the landscape and identified the primary hindrances to restoring this component at Kathio. A successful restoration program at Kathio State Park can be measured by the proportion of planted seedlings that are able to survive and eventually become mature trees. Data from this study suggests that methods to deter browsing should be continued at Kathio. Further research on

under- and overstory competition and associated browsing, insect, and other disease prevalence at these locations should be conducted. Additional research should also be conducted on pine bark adelgids, their control, and identifying high quality seedlings that are less susceptible to adelgid infestations.

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